A QUANTITATIVE STUDY OF THE GOLGI APPARATUS IN SPINAL GANGLION CELLS

W. P. COVELL

Laboratories of the Rockefeller Institute for Medical Research, New York

FOUR FIGURES

The first paper of this series (Covell, '26) dealt with the nucleocytoplasmic ratio in the renal tubule. It was found that the ratio was characteristic for each segment and that it was greater in the convoluted tubules than in the limbs of the loop of Henle.

Some observations with Doctor Cowdry, which will soon be reported, show that this change is accompanied by a distinct reduction in the mitochondria-cytoplasmic ratio. It is well known that the cells of the different segments are likewise physiologically different in the part which they play in urinary secretion, in their response to poisons, vital dyes, and other experimental methods of analysis. What these modifications in cellular structure mean we do not know, but it seems profitable to attempt to ascertain which elements, or ratios, vary dependently and which vary independently; in other words, to study the integrative action of the cell.

Obviously, the relations may be expressed in terms of surface or of volume, so that one has some ten or more variables to deal with. It is interesting to note, in this connection, that Ponder ('26) has established the existence of an interesting and perhaps significant relation between the surface area of the surfaces of the nucleus, zymogen granules, and mitochon-count. Du Noüy and Cowdry ('27) have attempted to study the surface of the nucleus, zymogen granules, and mitochondria in the acinous cells of the pancreas.

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The Golgi apparatus, however, seems to have been wholly neglected. It is with it that this paper is concerned. At first, attempts were made to study this structure in the cells of the renal tubule and to correlate the findings with the observations referred to, but this proved impracticable for several reasons. The strands of the network in these cells are of variable thickness, making quantitative estimation difficult and there was always the question whether all of the material actually present was faithfully preserved. In order, at least, to work under the most favorable conditions, the spinal ganglion cells of young mammals were chosen as material, because in them the Golgi apparatus may be demonstrated with unparalleled clearness and constancy.

MATERIAL AND METHODS

Ganglia in the cervical and lumbar enlargements were removed from seven rabbits two and a half to four weeks of age and from one adult rabbit, and fixed for twenty-four hours in Kolatchev's fluid, as modified by Nassonov ('24). They were then transferred to 2 per cent osmic acid and kept at 37½°C. for eight to nine days. Following dehydration and clearing, the tissues were embedded in paraffin and serial sections were cut 5 μ in thickness.

Every effort was made to employ photographic methods, and good photomicrographs were secured, which illustrate the general appearance of Golgi apparatus (figs. 1 and 2); but the photographs could not be used as a basis for the detailed measurements required, because they give information only concerning a single optical plane, whereas the whole depth of the section must be taken into consideration. The photographs are, furthermore, imperfect in the sense that the outlines of the Golgi apparatus in them are less distinct than in the original preparation, for the reason that strands of the apparatus which lie above and below the optical plane of the photomicrograph are blurred. An Edinger projection apparatus was tried, but did not prove helpful, because constant checking up of the projected outlines with the actual preparation was impossible.

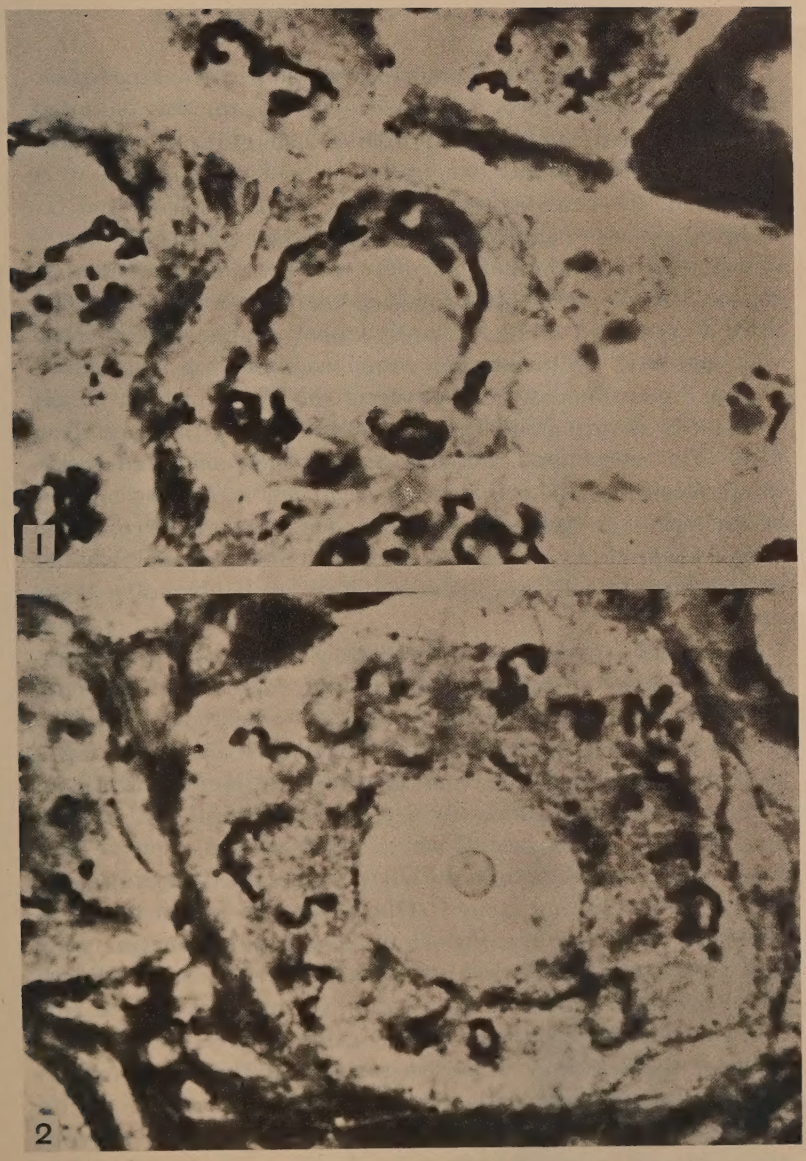

Fig. 1 Photomicrograph of Golgi apparatus in small-sized spinal ganglion cell. × 2000.

Fig. 2 Photomicrograph of Golgi apparatus in large-sized spinal ganglion cell. × 2000.

Accordingly, the more laborious method of making drawings at the table level with a camera lucida was adopted, with an optical combination yielding a magnification of 3050 diameters. In this way twenty-five cells of various sizes were examined, the boundaries of the cell, of the nucleus, and the Golgi apparatus being outlined. Every section of a cell was drawn, and since the number of sections was dependent upon the size of the cell, this proved a useful means of checking up the calculated diameters. The mean diameter of the cell was obtained by measuring in microns several arbitrarily chosen dimensions of the drawing of the largest section of the cell and by dividing the figure thus obtained by the magnification. The cell volume and surface were then computed on the assumption that the cell was spherical in form. The nucleus of each cell was treated in a similar manner. An error, however, unavoidably remains through the impossibility of measuring the cell processes, but it is probably not a large one.

The surface and volume of the Golgi apparatus were computed as for a tube of constant diameter. As a result of many measurements, this diameter was found to be about 0.4 μ. The length was quickly and accurately measured by employing a map-measuring machine, manufactured by Keuffel & Esser. This instrument is commonly used by cartographers. It consists essentially of a small wheel which is run over the outlines and which registers the distance traveled on a dial, in both centimeters and inches. Obviously, the actual length is somewhat greater than the length as measured in this way, because the strands extend at various angles through a depth equal to the thickness of the section, so that they have a certain vertical length added to the length projected on the single plane of the drawing. It is recognized also that the measurements apply only to cells prepared by this method, not to living cells. The volume of fluid displaced by the nervous tissue after fixation, dehydration, clearing, etc., was found to be 14 to 18 per cent greater than the amount displaced by the same tissue before fixation. Because the various cellular

components respond differently to fixatives, a certain differential shrinkage (or swelling) may conceivably occur; but this must be set aside for the present.

RESULTS

The data thus secured were treated in several different ways. When the surface area and the volume of the Golgi apparatus were plotted against the diameter of the cell, a tendency toward a shallow concave curve resulted in each instance (figs. 3 and 4). This curve was found to be approximated by means of the formula, $Y = a X^b$, where Y is the surface area or the volume of the Golgi apparatus, X the diameter of the cell in μ, and a and b constants, empirically determined. The data were fitted to curves by means of the method of averages. A more perfect correspondence was obtained by eliminating cell no. 21 (table 1) from the calculations, although the observations for this cell are included in figures 3 and 4.

Various ratios were computed in order to ascertain if the surface or volume of the Golgi apparatus varied relatively with the surface or volume of the cell or nucleus and the volume of the cytoplasm. Thus the computed surface area of the Golgi apparatus was divided by the computed surface area of the cell and likewise by that of the nucleus.

In table 1 the cells are arranged according to their size. They range in diameter from 17.86 μ to 54.92 μ. The nuclear diameter varies from 9.67 μ to 19.67 μ. The surface of the Golgi apparatus varies from 476.18 sq.μ in the smallest cell to 5587.72 sq.μ in the largest cell and the volume from 58.55 cu.μ to 691.97 cu.μ.

The surface area of the Golgi apparatus divided by the surface area of the cell gives a figure of fair agreement for all twenty-five cells on which determinations were made. The mean ratio is 0.511, or the surface of the Golgi apparatus is roughly one-half as great as the surface area of the cell. The absolute departure of all of the ratios from the mean is 0.053 and the relative deviation is 10.5 per cent.

The surface area of the Golgi apparatus divided by the surface area of the nucleus gives a ratio which varies with the size of the cell. Thus, in the smaller ganglion cells the surface of the Golgi apparatus is from one and one-half to three times that of the nucleus, and in the largest cells it is even greater in proportion, ranging from about four to nearly seven times.

The amount of cytoplasm, in terms of volume, when divided into the figure for the surface area of the Golgi apparatus and multiplied by 100 gives a ratio which decreases in magni-

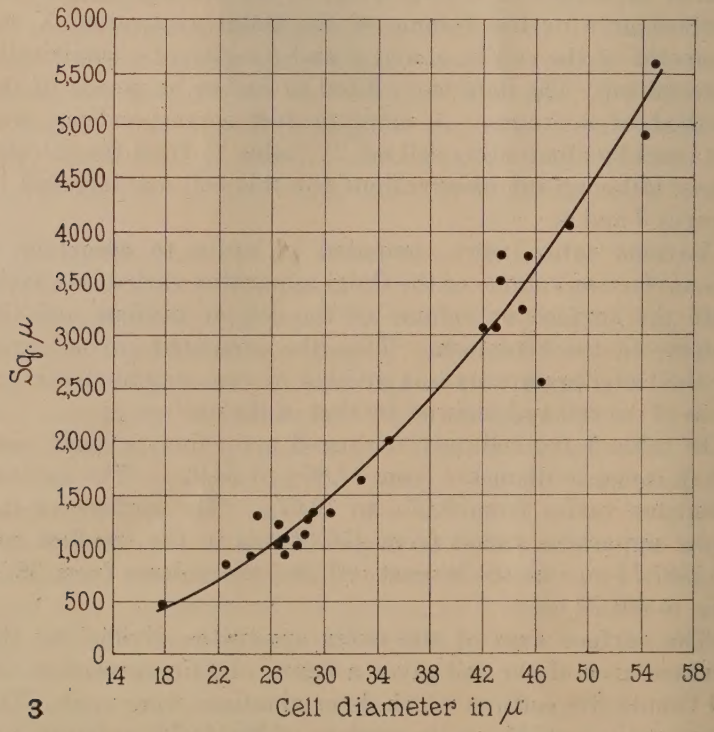

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Fig. 3 Graph with curve illustrating the relationship of surface area of Golgi apparatus to cell diameter. Abscissae: cell diameter in microns. Ordinates: surface area of the Golgi apparatus in sq.μ. Individual observations indicated by dots.

tude as the cell size increases. There is, then, relatively greater surface area of Golgi apparatus per volume of cytoplasm in the smaller cells than in the larger.

The volume of the Golgi apparatus divided by the volume of the cell and likewise by the cytoplasmic volume and multiplied by 100 gives ratios which decrease in magnitude with an increase in cell or cytoplasmic volume. The ratio pertain-

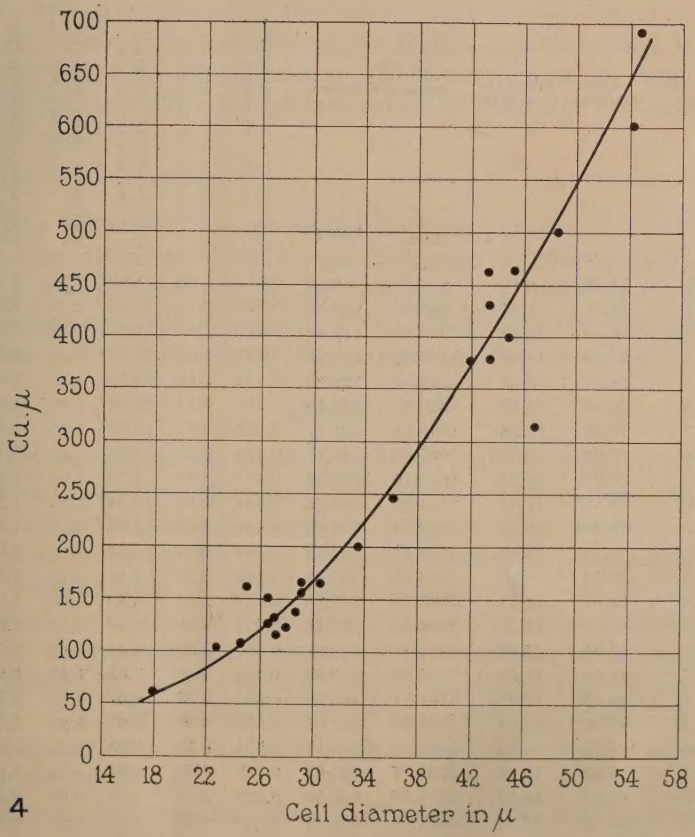

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Fig. 4 Graph with curve illustrating the relationship of volume of Golgi apparatus to cell diameter. Abscissae: cell diameter in microns. Ordinates: volume of Golgi apparatus in cu.μ. Individual observations indicated by dots.

ing to cell volume is less than that for cytoplasmic volume, since the volume of the nucleus is not considered in the latter ratio.

Figure 3 is a shallow concave curve resulting from the plotting of the surface area of the Golgi apparatus against

TABLE 1

NO. OF CELL	CELL DIAMETER	NUCLEAR DIAMETER	GOLGI APPARATUS		$\frac{\text{SURFACE OF GOLGI APPARATUS}}{\text{SURFACE OF CELL}}$	$\frac{\text{SURFACE OF GOLGI APPARATUS}}{\text{SURFACE OF NUCLEUS}}$	$\frac{\text{SURFACE OF GOLGI APPARATUS}}{\text{VOLUME OF CYTOPLASM}} \times 100$	$\frac{\text{VOLUME OF GOLGI APPARATUS}}{\text{VOLUME OF CELL}} \times 100$	$\frac{\text{VOLUME OF GOLGI APPARATUS}}{\text{VOLUME OF CYTOPLASM}} \times 100$
			Surface area	Volume					
	μ	μ	$sq.\mu$	$cu.\mu$					
1	17.86	9.67	476.18	58.55	0.475	1.62	18.96	1.96	2.33
2	22.78	11.31	849.02	104.39	0.521	2.11	15.62	1.68	1.92
3	24.59	12.13	910.82	111.98	0.479	1.97	13.27	1.44	1.63
4	25.08	11.96	1310.50	161.13	0.663	2.92	17.79	1.95	2.19
5	26.55	10.65	1043.54	128.30	0.471	2.93	11.39	1.31	1.40
6	26.64	12.62	1220.84	150.10	0.547	2.44	13.80	1.52	1.69
7	27.04	13.28	1093.18	134.41	0.476	1.97	11.98	1.30	1.47
8[1]	27.21	10.33	947.29	116.47	0.408	2.83	9.51	1.10	1.17
9	28.03	13.11	1013.15	124.56	0.411	1.88	9.79	1.08	1.20
10	28.52	13.11	1134.22	139.45	0.444	2.10	10.34	1.15	1.27
11	28.80	13.11	1288.72	158.45	0.494	2.39	11.37	1.27	1.40
12	29.18	14.10	1339.88	164.74	0.501	2.14	11.61	1.26	1.43
13	30.40	12.62	1345.96	165.48	0.463	2.69	9.85	1.13	1.21
14	33.67	14.10	1633.70	200.86	0.459	2.61	8.83	1.00	1.09
15[1]	35.08	15.73	2016.16	247.89	0.521	2.59	9.80	1.10	1.20
16	41.96	15.00	3081.48	378.87	0.557	4.36	8.35	0.98	1.03
17	43.44	15.08	3097.69	380.86	0.522	4.30	7.53	0.88	0.92
18	43.60	15.08	3768.91	463.39	0.631	5.27	9.06	1.07	1.11
19	43.60	17.04	3520.68	432.87	0.589	3.86	8.63	0.99	1.06
20	45.08	14.75	3262.33	401.11	0.511	4.78	7.05	0.84	0.87
21	45.49	16.39	3789.17	465.88	0.583	4.50	8.07	0.94	0.99
22	46.55	16.06	2571.87	315.59	0.378	3.17	5.08	0.60	0.62
23[1]	48.52	17.38	4067.78	500.14	0.550	4.28	7.13	0.83	0.87
24	54.16	15.90	4908.69	603.53	0.532	6.18	6.05	0.72	0.74
25[1]	54.92	19.67	5587.72	691.97	0.589	6.75	4.60	0.79	0.83

[1] Cell of an adult rabbit of 2450 grams body weight.

the diameter of the cell. This curve may be approximately expressed by means of the formula:

$$\text{Surface area of the Golgi apparatus in sq.}\mu\ (\times 100) = 68.72\ (\text{cell diameter, }\mu)^{2.234}$$

The absolute deviation of the observed from the calculated values is 160.5 sq.μ and the relative deviation is 8.2 per cent. The calculated surface area of the Golgi apparatus for a cell of 20 μ in diameter is 553.9 sq.μ. For one of 35 μ it is 1933.2 sq.μ and in a cell of 50 μ the surface area is 4291.0 sq.μ.

In figure 4 the volume of the Golgi apparatus has been plotted against cell diameter. This curve may be numerically expressed in approximate terms by means of the empirical formula:

$$\text{Volume of the Golgi apparatus in cu.}\mu\ (\times 100) = 8.738\ (\text{cell diameter, }\mu)^{2.234}$$

The calculated volume of the Golgi apparatus of a cell of 20 μ in diameter is 70.4 cu.μ, for one of 35 μ it is 245.9 cu.μ, and in a cell of 50 μ in diameter it is 545.8 cu.μ. The average absolute deviation of the observed from the calculated values is 19.7 cu.μ. The percentage deviation is 8.9.

DISCUSSION

The measurements seem to indicate that the Golgi apparatus is susceptible of quantitative study. The surface which the apparatus affords, in spinal ganglion cells, is about one-half as large as the total surface of the cell. The relation of surface area of Golgi apparatus to cell diameter may, indeed, be expressed in the form of a curve which is numerically approximated by means of the formula for a simple parabola, $Y = a X^b$ (fig. 3). What this may signify I am at present wholly unable to say. Such a definite relation does not apparently exist between the Golgi apparatus and the nucleus (table 1).

These observations have, of necessity, been made on cells impregnated with osmium. The condition of the Golgi apparatus in the living cells of mammals is unknown. Parat ('24) and his associates state that it occurs in the form of a

series of vacuoles capable of being stained with neutral red. The principal evidence advanced consists of a topographic correspondence between the vacuoles in supravitally stained cells and the blackened networks brought to light in fixed cells by the action of osmic acid. The actual changes in the vacuoles resulting from fixation and leading to the formation of a typical Golgi apparatus have never been followed. Quantitatively, a difference seems to exist, because in nerve cells the neutral-red vacuoles are not particularly abundant, while the Golgi apparatus, as revealed in osmium preparations, is unusually highly developed. Further information is urgently needed. Whether or not it is represented by a series of vacuoles, the general configuration of the Golgi apparatus in the living cell must correspond substantially with that revealed by methods of impregnation with osmium, because by counterstaining these preparations it may be observed that the mitochondria (which are easily observed during life) are not noticeably displaced. There have been no massive movements of cellular contents.

As to the function of the Golgi apparatus, very little may be said. It seems clear, however, that there is some measure of discontinuity between its substance and that of the surrounding cytoplasm; in other words, that a gradual transition from one to the other does not occur. Such a surface or interface between materials of different character may be active in processes of adsorption and synthesis—as the mitochondria-cytoplasmic surface film is believed to be (Cowdry, '26)—though in a different way, depending upon the physicochemical composition of the surface.

Very recently, it has been stated that the Golgi apparatus is definitely concerned in the formation of secretion antecedents in gland cells (Nassonov, '24; Bowen, '26, etc.). A few years ago this rôle was just as forcibly attributed to the mitochondria, and at a still earlier date to the nucleus and certain extranuclear substances, presumably derived from it. All of which is probably true up to a certain point and nothing less than one would expect, for, in discharging its principal func-

tion, it is natural to suppose that the cell mobilizes its entire machinery. But it is too early to disconnect in our imagination, with any measure of confidence, this machinery and to assign definite and exclusive rôles to the Golgi apparatus, mitochondria, or any other cellular components.

SUMMARY AND CONCLUSIONS

1. The Golgi apparatus may be studied quantitatively in successful preparations of spinal ganglion cells.

2. The computed surface area of the Golgi apparatus is approximately one-half as large as the total cell surface.

3. There is relatively a greater surface area of Golgi apparatus in small cells in relation to cytoplasmic volume than in large cells.

4. In small cells there is relatively less Golgi apparatus surface in relation to nuclear surface than in large cells.

5. There is relatively more volume to the Golgi apparatus of small cells in relation to cell and cytoplasmic volumes than in large cells.

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THE CHARACTER OF THE WALL OF THE SMALLER BLOOD VESSELS IN THE BONE MARROW OF THE FROG, WITH SPECIAL REFERENCE TO THE QUESTION OF ERYTHROCYTE ORIGIN

H. E. JORDAN AND J. P. BAKER, JR.
Laboratory of Histology and Embryology, University of Virginia

FOUR PLATES (TWENTY FIGURES)

INTRODUCTION

The nature of the endothelial wall of the capillaries and sinusoids of red bone marrow assumes a position of primary importance because of its relation to the problem of the mode of delivery of the differentiating erythrocytes into the vascular channels. If this wall is fenestrated, there exists no definite barrier to the entrance of extravascularly differentiating blood cells. If the wall is complete, then the mechanical difficulties of the transfer of the non-ameboid erythrocytes present a major problem.

Bunting ('05), Maximow ('10), and Drinker ('20) have assumed that the extravascularly ripening erythrocytes are forced through temporary breaches in the continuous vascular wall by a growth pressure. Van der Stricht ('92), in his study of the bone marrow of the pigeon, came to the conclusion that here the vascular wall is intact. The erythrocytes are said to develop within 'hemopoietic capillaries,' which only secondarily make connections with the venous sinuses. In the case of the rabbit, he concluded that the wall of the medullary blood vessels is incomplete and that the erythrocytes here develop from reticulum cells. The red cells in such marrow are secondarily transferred from their extravascular location to the lumen of the venous sinusoids through openings in the endothelial wall.

Doan, Cunningham, and Sabin ('25), on the basis of a microscopical study of injected specimens of experimental hypoplastic marrow of pigeon and rabbit, conclude that both in birds and mammals the vascular wall is complete and that erythrocytogenesis is exclusively a matter of the intravascular differentiation of endothelial cells. They claim that in the depleted marrow the venous sinusoids are connected by collapsed capillaries, and that the endothelium of these capillaries is the source of origin of the erythrocytes in hyperplastic marrow. Peabody ('26) makes the same claim for human marrow from a case of typhus fever. In view of much evidence that erythrocytes originate also from cells of reticular tissue, the questions of the relation of endothelium to reticulum cells in red bone marrow and of the vascular lumen to the intercellular spaces of the reticular stroma cannot yet be considered as finally settled. Recent studies of the reticulo-endothelial system (Aschoff) also have shown the intimate structural relationship and interchangeable functional capacity of endothelial cell and reticulum cell. Our own experience with the microscopic study of various avian and mammalian marrows, both in the depleted and active conditions, has inclined us to the belief that the persistent discrepant claims regarding the character of the vascular wall of bone marrow and the origin of medullary erythrocytes are the result largely of the relatively unfavorable nature of avian and mammalian marrows for the investigation of these problems. Accordingly, we have directed our attention to amphibian bone marrow.

The femoral marrow of the frog furnishes a very superior material. This marrow is normally, except for a brief period after hibernation, in a hypoplastic condition. Hyperplastic marrow may be obtained experimentally in a small number of frogs by splenectomy. Satisfactory India-ink injections are relatively easy to obtain. Most important of all, the marrow cells are much larger and generally much less densely packed. Our evidence shows unequivocally, we believe, that in the femoral marrow of the frog the lumen of the venous

sinusoids is continuous with the intercellular spaces of the reticular stroma and that here erythrocytes take origin exclusively from reticulum cells or their lymphocyte derivatives.

DESCRIPTION

a. Hyperplastic marrow

The hemopoietically active marrow was secured from a frog splenectomized eighty-six days previously. This marrow (fig. 3) was described in a study of the hemopoietic effects of splenectomy (Jordan, H. E., and Speidel, C. C., '23) and in another on the experimental production of osteoclasts (Jordan, '24). In compensating for the spleen, which is the chief erythrocytopoietic organ of the frog, the ordinarily white marrow changed to a hyperplastic condition. This material is not especially favorable for a solution of the problems concerning the character of the blood-vessel wall or the spatial relation of endothelium to reticular tissue cells. But it does show very clearly that erythrocytes arise only from reticulum cells. Cells separate from the reticular stroma, assume spheroidal shape, and subsequently elaborate hemoglobin. The early intermediate stage between reticulum cell and the erythrocyte is the hemoblast, indistinguishable from the lymphocytes of adjacent blood vessels (figs. 16 to 20). The reticulum cells give little evidence of proliferation, but lymphocyte derivatives in mitosis are abundant. Not a single endothelial cell in mitosis could be found. Only an occasional hemoblast (lymphocyte) differentiates into a granulocyte.

Only a relatively slender core of the marrow remains acellular. This area contains practically no fat. The reticular stroma is richly invaded by capillary branches of the central artery and vein. Their peripheral ramifications are thoroughly masked by the closely aggregated hemoblasts. Nearer the epiphyses, the peripheral shell of hemoblasts becomes narrower, and along its axial border occur many sinuses engorged with blood, the constituent cells including

all stages in the differentiation of erythrocytes from lymphocytes. Certain more peripheral sinuses contain lymphocytes almost exclusively (fig. 19). These cells are considerably smaller than the extrasinusoidal more typical hemoblasts. Other sinuses contain variable proportions of lymphocytes, erythrocytes, and intermediate stages (fig. 20). The clumps of lymphocytes are enveloped with a membrane apparently endothelial, but of stromal origin (figs. 16, 17, and 18). Many of these clumps contain a variable number of erythrocytes peripherally, suggesting that these areas are connected with blood vessels (figs. 18 and 19). In other areas, some of considerable size, lymphocytes and erythrocytes are intermingled in such intimate and random fashion as to preclude an interpretation in terms of the inclusion of the erythrocytes within blood vessels.

b. Hypoplastic marrow

Except for a very narrow peripheral layer of granulocytopoietic tissue, this marrow is predominantly fatty (figs. 1 and 2). The reticular stroma occurs in only meager amounts among the large fat-cells; peripherally, it is relatively more abundant. This marrow contains an extensive system of arterioles, venules, and connecting capillaries. The venules may be appropriately designated venous sinusoids. In general, the arterioles contain a variable number of erythrocytes; the venules and capillaries are more commonly empty, except for an inconstant number of lymphocytes. These lymphocytes appear more abundantly next the endothelium.

The peripheral granulocytopoietic tissue, different in amount in different individuals, is generally more extensive along the epiphyseal borders. Here occur also a variable number of osteoclasts and patches of variable size in which the cells are in stages of degeneration (fig. 2). Especially along the epiphyseal border appear also collections of hemoglobin débris; obviously, senile red blood cells undergo dissolution here. A certain number of red cells occurs mingled

with the granuloblasts of these areas (fig. 15). This fact alone would suggest an open vascular wall in these granulocytopoietic areas. Where granuloblasts are few in number or absent for variable extents peripherally along the diaphyseal marrow, this area assumes the character of a peripheral sinus, continuous with the more centrally lying vascular net (fig. 14). It is filled with a homogeneous substance tinctorially identical with that which fills the blood vessels. It no doubt represents blood plasma.

The most interesting and important fact about this white marrow relates to certain areas where the vascular lumen is continuous with an extensive system of intercellular spaces among the fat-cells (figs. 4 and 5). Here the endothelium is directly continuous with the reticulum cells of the medullary stroma. This area represents true reticulo-endothelium. Both the reticulum cells and the fat-cells contain a spheroidal cytoplasmic vacuole adjacent to the nucleus (fig. 8). The interlipocellular spaces suggest the so-called 'collapsed capillaries' described by Doan, Cunningham, and Sabin for pigeon and rabbit marrows and by Peabody for man. But in the frog's marrow these connecting channels between adjacent venous sinusoids are clearly intercellular spaces. Quite distinct capillaries can be clearly traced in these same regions (fig. 8). Even on the basis of the evidence from this uninjected tissue one would be compelled to conclude that the vascular lumen is continuous with the intercellular stromal spaces. In fact, the plasma itself constitutes an injection mass. In other words, a continuity of plasma between venous sinusoid and peripheral sinus, on the one hand, and between the venous sinusoids or capillaries and intercellular stromal spaces, on the other, demonstrate a fenestrated structure for the endothelial wall (fig. 5). The hyperplastic marrow demonstrates the origin of erythrocytes exclusively from reticulum cells or intermediate lymphocytes. Since the stromal spaces in which these erythrocytes differentiate are directly continuous with the vascular channels, the transfer of these red cells to the blood vessels is readily accomplished.

Mechanically, it amounts to the same thing as if erythrocytopoietic 'collapsed capillaries' did actually connect with the venous sinuses.

A sharp difference exists between the capillaries directly continuous with the precapillary arteries (arterioles) and those which represent direct radicles of the venous sinusoids. The arterioles and their capillaries are definitely closed channels (fig. 8). The sinusoids and their capillary branches are open to the stromal spaces at intervals of the adjacent fat-cells (fig. 5). Certain sinusoids, especially along the periphery, contain irregular areas of variable size of degenerating cells, including reticular cells, hemoblasts, and erythrocytes. These areas probably represent retreating masses of abortive hemopoietic tissue following the posthibernation temporary hyperplasia.

c. Injected depleted marrow

The above conclusion, namely, that in the femoral marrow of the frog the sinusoidal lumen is directly continuous with stromal tissue spaces is definitely confirmed by the results of injections with a suspension of India ink. The technic was as follows: a frog was lightly anesthetized with ether, the thorax opened, and the heart exposed. Higgins India ink diluted with an equal amount of water was injected under light pressure from a syringe directly into the ventricle. The pulsations of the heart, continuing for approximately two minutes, forced the ink throughout the vascular system, and thus secured a beautiful injection of the white marrow. The less perfectly injected specimens afforded the most favorable tissues for this study. The amount of ink suspension was approximately 8 cc. Only fresh frogs gave satisfactory injections; frogs that had been in the laboratory for some time did not possess sufficiently strong heart action to carry the injection to the bone marrow.

It needs to be emphasized, in view of the results, that only sufficient pressure was exerted on the syringe to produce a very gradual mingling of the India ink with the heart blood.

The addition of as much as 8 cc. India-ink suspension over a period of two minutes, however, no doubt raised the blood pressure somewhat. This might be expected to rupture the finer, thin-walled capillaries of the marrow. An effort was made to neutralize this increase in blood pressure by section of the abdominal vein before the injection. This procedure effected a relief of pressure, as demonstrated by a free flow of ink-colored blood from the vein. Furthermore, even in the most completely injected specimens, sections of the lungs showed no extravasation of ink from the capillaries. As a further precaution against possible pressure artifacts, only specimens with a partial marrow injection were employed in this study.

Sections of these injected specimens showed that in the more centrally placed larger blood vessels the ink was sharply limited by the endothelial wall (fig. 6). More distally occurred irregularly triangular masses of ink, filling funnel-shaped projections from the sinusoids; these extended for variable distances into the reticular stroma (figs. 7 and 9). In still other regions the ink encircled fat-cells (figs. 10, 12, and 13), partially filling the pericellular space. The ink is sharply outlined next the fat-cell, unevenly contoured peripherally. In other regions, at variable distances from the nearest blood vessel, occur large irregular masses of ink directly within the stroma (fig. 11). These same intercellular spaces may contain also scattered erythrocytes and hemoblasts. Similarly, along the central border of the peripheral sinus (or granulocytopoietic layer) occur irregular masses of ink (figs. 14 and 15). In specimens with more complete injections this area becomes filled with ink over large areas. Even the lacunae of the overlying bone contain a variable amount of ink. There is apparently a connection also between this peripheral sinus and the bone lacunae.

DISCUSSION

The femoral marrow of the frog furnishes a superior material for the study of the character of the vascular bed

and the identification of the red-cell ancestor. Conditions here differ sharply from those prevailing in the marrow of birds and mammals, as described by Doan, Cunningham, and Sabin ('25) and in man as described by Peabody ('26). They agree, however, with the earlier description of Van der Stricht ('92) for the marrow of the rabbit. In the frog, sinusoid lumen and stromal tissue space constitute a unit system, and endothelium is continuous with reticulum-cell membrane. The erythrocyte ancestor is a lymphocyte, derived from a reticulum cell. Endothelium appears to have no erythrocytogenic capacity in this marrow. According to Doan, Cunningham, and Sabin, the blood-vessel wall of avian and mammalian marrow is everywhere complete, and the erythrocytes take origin only from endothelial cells of 'collapsed capillaries' connecting adjacent venous sinusoids. The variable origin of erythrocytes—from reticulum cell, as in amphibian spleen and marrow; from endothelium, as in the marrow of pigeon and rabbit (Doan, Cunningham, and Sabin)—may be explained on the basis of a close genetic relationship between endothelium and reticular tissue, and the relatively slight degree of differentiation of both with respect to the parent polyvalent mesenchymal cell. The conclusion of a reticulum-cell origin of the erythrocyte in frog's marrow and spleen is supported also by the description of tissue cultures of axolotl spleen by Chlopin and Chlopin ('24).

In the frog the spleen is practically the sole erythrocytopoietic tissue for the greater part of life. Only for brief periods immediately following hibernation and during early postlarval life, when the enchondral bones are forming, does the marrow assume any considerable degree of erythrocytogenic activity. Ordinarily, the marrow is active only in granulocyte production, and this activity is confined to a narrow peripheral area, more pronounced along the epiphyseal border of the shaft. The ancestor of both erythrocyte and granulocyte is the lymphocyte. The lymphocytes may mature into definitive red cells to a small extent even in the peripheral circulation. However, the erythrocyte ripens

chiefly in the spleen, to a lesser extent in the sinusoids of the liver and marrow; the granulocyte differentiates chiefly in the peripheral area of the marrow, to some extent in the stroma of the kidney. In hypoplastic femoral marrow of the frog, the lymphocytes of the venous sinusoids are disposed peripherally, in many cases forming a complete lining for a considerable distance as seen in sections.

Experimental regenerating, erythrocytopoietically active femoral marrow may be produced in the frog by splenectomy. Removal of the spleen eliminates the chief erythrocytopoietic organ, and in a certain number of frogs compensation is attained by marrow hyperplasia. Such marrow is especially favorable for an analysis of the conditions underlying erythrocytopoiesis in contrast with granulocytopoiesis. In this hyperplastic marrow only very few granulocytes (eosinophils) occur. They develop from lymphocytes or directly from reticulum cells. They occur generally as widely scattered solitary cells. Occasionally they may be seen in strings of from four to eight cells. The erythrocytes also develop from lymphocytes, of reticulum-cell ancestry, but they frequently occur in the form of spheroidal or cord-like clumps. The cells of such clumps, or 'blood islands' (figs. 16, 17, and 18), are smaller than the lymphoid cells (hemoblasts) of the major portion of the hemopoietic tissue. These clumps of small lymphocytes represent proliferation products of larger lymphocytes. The surrounding reticular stroma becomes modified into a reticular membrane indistinguishable from endothelium (fig. 17). Within such 'hemopoietic capillaries' (Van der Stricht, '92) lymphocytes ripen into erythrocytes. All gradations can be traced between such 'blood islands' consisting only of lymphocytes enveloped by reticulum and those consisting of a variable number of mature erythrocytes in a typical endothelium-lined sinus (figs. 16 to 20).

Since tissue spaces are everywhere continuous with the lumens of venous sinusoids, the ripening erythrocytes, as they separate from the loosening mass of lymphocytes, have ready access, borne by the moving plasma, to the blood

vessels. That such is actually the mode of delivery of the ripening erythrocytes to the venous sinusoids is further indicated by the presence peripherally, in many of these clumps of lymphocytes, of definitive erythrocytes. This difference in the mode of development of erythrocytes and granulocytes, the former generally in clumps within reticulum-lined or endothelium-lined spaces, the latter generally singly in tissue spaces, supports our earlier conclusion that a relatively high concentration of carbon dioxide is the effective stimulus for erythrocytogenesis. The fact of the origin of erythrocytes almost exclusively in the spleen for the greater part of life of the frog is in strict conformity with this hypothesis. In the spleen the open vascular system provides a sluggish blood current, effecting a relatively high concentration of carbon dioxide; similarly, in other regions of sinusoidal circulation, as in the liver, kidney, and marrow, conditions are relatively favorable for the erythrocytic differentiation of lymphocytes.

The frog material demonstrates clearly the erythrocytogenic capacity of the lymphocyte. Alder and Huber ('23) have described this same cell in amphibia and reptiles as the ancestor of red cells, chiefly in the spleen, liver, and bone marrow. They claim, however, that this cell is not a true lymphocyte, but a 'hemocytoblast.' But the cell has all the morphological and tinctorial characteristics of the typical mammalian lymphocytes, and there would seem to be no real basis for the conclusion that lymphocytes do not occur below birds. Even in certain lymph nodes of the rabbit, under certain conditions (Jordan, '24, '25) lymphocytes become transformed into erythroblasts, and reticulum cells into endothelium. Reticulum, endothelium, and lymphocyte would seem to constitute the specific elements of a complete reticuloendothelial system, each with identical polyvalent functions—phagocytic, erythrocytogenic, and granulocytopoietic (Jordan, '27)—explicable on the basis of a relatively slight degree of differentiation and their close genetic relationship through their common mesenchymal ancestor.

The illustrations of hypoplastic marrow of pigeon and rabbit (Doan, Cunningham, and Sabin) and man (Peabody) resemble so closely appearances in comparable marrow from the frog, that one cannot escape the suggestion that conditions are essentially identical. What have been described as endothelial cells in the spaces between the fat-cells correspond in position and appearance with cells which we interpret as reticulum cells. In the case of the hypoplastic marrow of the frog's femur the nuclei of the endothelial cells are long, straight, finely granular, fusiform elements (fig. 8). The nuclei of the fat-cells are similar, but generally somewhat stouter. The reticular cells are irregularly polygonal bodies, with spheroidal nucleus. The latter generally contain a nucleolus. The color of the nucleus, in hematoxylin-eosin-stained sections, varies from a pale blue, like that of the fat-cell, to a purple color, like that of some of the lymphocytes. Both fat-cells and reticulum cells generally contain a cytoplasmic vacuole, frequently of sufficient size to indent the nucleus (fig. 8). Such a cytoplasmic vacuole does not appear in the endothelial cell, but is occasionally present in lymphocytes (hemoblasts) at early stages of their differentiation from reticulum cells.

The areas which Peabody ('26) describes as 'intersinusoidal capillaries,' lined with endothelium, we interpret as intercellular spaces of the reticular stroma, lined with reticulum cells (reticulo-endothelium). Peabody admits the difficulty in his material of distinguishing between nuclei of fat-cells, reticulum cells, and endothelial cells. "The nuclei of the fat cells," he says, "are not at all prominent, and the reticular cells described by Sabin are rare and difficult to distinguish." Certain of Peabody's figures (e.g., 8, 10, and 11) show the same peculiar condition of the spaces enveloping the fat-cells as is revealed by our India-ink injections, namely, that it is not an annular channel, but an actual double-walled spheroidal sac. Red blood corpuscles, like the injected ink, lie over the sectioned fat-cell as well as around the periphery. In fixed tissues this enveloping space is exaggerated through

the contraction of the fat-cell. This largely artificial space is nevertheless more or less completely filled by India ink which entered from the venous sinusoid with which the space connects (figs. 9, 10, and 12). If this space actually contained a capillary continuous with the venous sinusoid, then the India ink in this location should appear as a narrow band with a sharp contour on both surfaces. The actual appearance accords better, we believe, with an interpretation of the perilipocellular areas as intercellular spaces than as intersinusoidal capillaries.

In one instance (fig. 9) Peabody shows a branching transition capillary (arterial capillary) traversing what he calls "a widely dilated intersinusoidal capillary." Such relationship between capillaries, one inside the other, would be most peculiar. The illustration bears better the interpretation, we think, of a capillary within a hemocytopoietic area of reticular stroma. Indeed, this interpretation is suggested also by the simile used to describe the later stages of hyperplasia, when "the intersinusoidal capillaries have become wide cell beds and their individual limits have become indistinguishable just as a series of brooks which flow through a field lose their identity when the spring floods cause them to swell until they merge and convert the field into a great lake." Obviously, the only thing the 'capillaries' could overflow into would be reticular stroma, and the resulting 'lake' would be in part at least composed of intercellular spaces of the reticular stroma.

The interpretation placed upon "the groups of megaloblasts situated along the outside of a venous sinusoid, between the sinus and an adjacent fat cell" also lacks convincing support. Stating that these 'megaloblasts' probably do not arise from the endothelium of the venous sinus, he attributes their origin to endothelium covering the fat-cell. It seems more in accord with our findings that the extremely narrow space between a fat-cell and the immediately adjacent endothelium of a venous sinusoid should contain a portion of the reticular stroma rather than a capillary parallel to and in contact with a venous sinusoid.

SUMMARY

1. In hypoplastic femoral marrow of the frog the venous sinusoids are directly continuous with the intercellular spaces of the fatty reticular stroma. The plasma content, which takes a light purple color after hematoxylin stain, furnishes a veritable injection mass and clearly outlines the complex reticulo-endothelial vascular bed. The stromal tissue spaces connect with the sinusoid lumens by conical projections, through which endothelium becomes continuous with reticulum cells. Many of the fat-cells adjacent to venous sinuses are completely encircled by a tissue space continuous with the blood-vessel lumen. Injections of white marrow with India-ink suspensions completely confirms this interpretation of the open character of the sinusoidal wall in frog's marrow.

2. Experimental hyperplastic marrow, following splenectomy, shows that erythrocytogenesis is a matter of the differentiation of lymphocytes originating from reticulum cells. These red-cell ancestors mature both within endothelium-lined and within reticulum-lined tissue spaces. The reticular stroma increases at the expense of the fat-cells. Reticular cells separate from the stroma, assume spheroidal shapes, and as lymphocytes are either swept into the venous sinuses to differentiate into erythrocytes or aggregate into clusters and differentiate in situ. The tissue space containing such maturing erythrocytes is in connection with a venous sinus, and its encircling reticulum-cell membrane is continuous with the endothelium of the sinus.

3. The vascular and erythrocytopoietic conditions are essentially identical in spleen and marrow of the frog. The wall of the venous sinuses is open to the intercellular spaces of the reticular stroma. The red-cell ancestor is the lymphocyte, of reticulum-cell derivation. The circulating lymphocyte may differentiate into an erythrocyte in the blood or tissue spaces of spleen and bone marrow.

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PLATES

PLATE 1

EXPLANATION OF FIGURES

1 Photomicrograph of median longitudinal section of the femur of the frog. This shows the usual hypoplastic condition of the marrow, an extensively vascularized adipose tissue. Hemocytopoietic activity, exclusively granulocytic, is practically limited to the epiphyseal borders and a very narrow peripheral area. The epiphysis (above) is enveloped by hyaline cartilage; below on the left border is a mass of skeletal muscle. × 20.

2 More highly magnified view of portion of figure 1. The darker blood vessels contain a variable amount of blood. Numerous erythrocytes scattered among the differentiating granulocytes along the epiphyseal border represent migrants from the blood vessels. On the right, near the upper and lower margins, appear two irregular masses of retreating (in part disintegrating) reticular connective tissue. Two similar masses occur along the epiphyseal border. These masses probably represent remnants of the erythrocytopoietic reticular tissue of the posthibernation hyperplastic condition, not yet fully displaced by fat. × 50.

3 Photomicrograph of transverse section of complete column of hyperplastic marrow from the femur of a splenectomized frog. The section is taken approximately midway between the middle of the diaphysis and the epiphyseal border. The hyperplastic condition of this ordinarily hypoplastic marrow (figs. 1 and 2) represents a compensatory reaction to the splenectomy performed sixty-eight days previously. Numerous osteoclasts occur peripherally. The greater portion of the marrow is hemopoietically active. The reticulum cells are differentiating largely into erythroblasts. The intermediate hemocytoblast stages are identical with lymphocytes. Many of the latter are in mitosis. The blood vessels apparently end in intercellular reticulum spaces peripherally, but the exact relation of endothelium to reticulum cannot be determined in this material on account of the compact arrangement of the cells and the apparently promiscuous mingling of erythrocytes and hemocytoblasts. There is no indication here of endothelial cell proliferation or differentiation into erythrocytes. The erythrocytes originate exclusively from lymphocyte-like reticulum-cell derivatives. Giemsa stain. × 125.

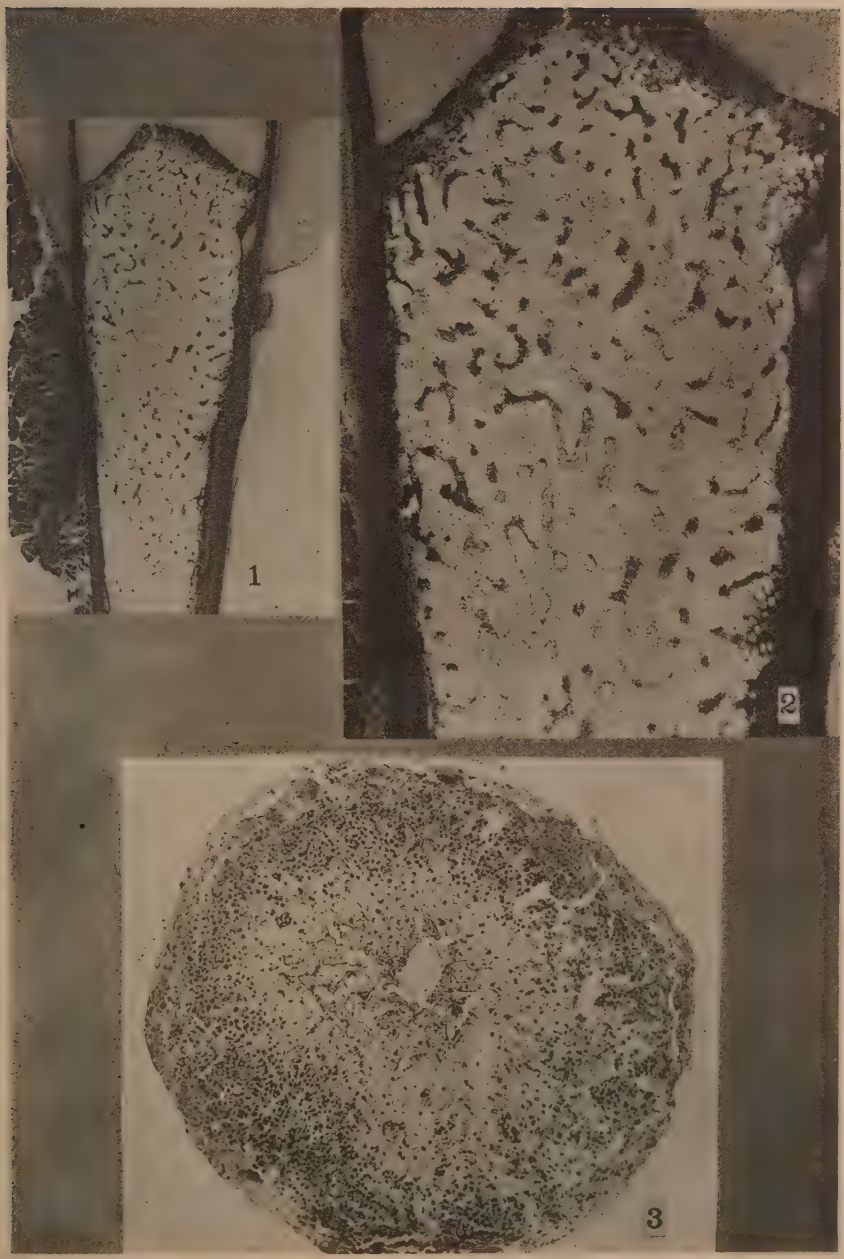
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PLATE 2

EXPLANATION OF FIGURES

4 Drawing of area from the same section shown in figures 1 and 2, but nearer the midpoint of the diaphysis. The reticular stroma is predominantly fatty. The venous sinusoids contain many lymphocytes, arranged for the most part peripherally. The lumen of the sinusoids is continuous in many places with the intercellular spaces of the reticular stroma. In such places the endothelium of the sinusoids is continuous with the reticulum cells of the adipose stroma. The luminal continuity is shown especially well in the left center, particularly between the two lower venous sinusoids (area labeled *A*). × 160.

5 Drawing under higher magnification of area *A* of figure 4, showing continuity between the lumen of the venous sinusoid and the intercellular spaces of the reticular stroma. Both venous lumen and intercellular spaces are filled with an identical content, coagulated plasma. This stains a light purple color in hematoxylin-eosin preparations. The venous sinusoid contains a few lymphocytes. At the left, above, is shown the nucleus of an endothelial cell; at the right, that of a fat-cell; and at the right, below the sinusoid, that of a reticular cell. Below the sinusoid the endothelium is continuous with the reticulum. The evidence even here, in uninjected marrow, demonstrates unequivocally a continuity between endothelium and reticulum cell, and between blood-vessel lumen and intercellular spaces of the reticular stroma. × 500.

6 Drawing of a small area of hypoplastic femoral marrow of the frog, after a cardiac injection of a suspension of India ink. The fat-cells have shrunken away from their boundaries of reticular tissue. The blood vessel (venous sinusoid) contains a small amount of India ink on the left, sharply limited by the endothelial wall. × 500.

7 Drawing of area of marrow, showing continuity between a venous sinusoid and the intercellular spaces of the reticular stroma. The injected ink outlines irregular reticulum spaces (above) continuous with the lumen of the sinusoid. × 300.

8 Drawing of a small area of uninjected hypoplastic femoral marrow, showing a long capillary from the arterial side of the vascular plexus. The capillary branches of the medullary arterioles have complete walls; only the venous sinusoids and their capillary branches have fenestrated walls, effecting a luminal continuity between blood-vessel and intercellular spaces of the reticular stroma. This illustration shows the differences between endothelial, reticulum, and fat-cells. The cytoplasm of the reticulum cell and the fat-cell generally contains a vacuole, frequently indenting the nucleus. The lower right-hand corner shows a venous sinusoid, containing a number of lymphocytes. Above this is a large intercellular stromal space, with a few reticulum cells and several lymphocytes. × 500.

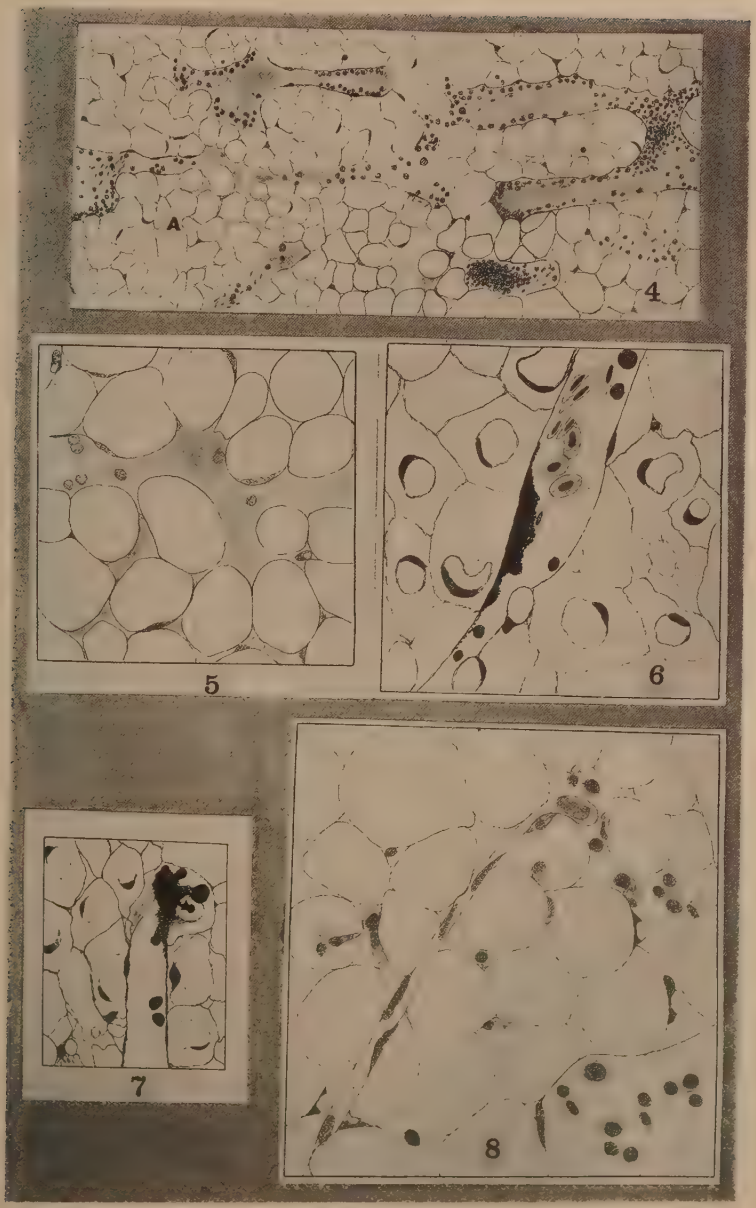
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PLATE 3

EXPLANATION OF FIGURES

9 Drawing of an area of injected femoral marrow, showing a branching venous sinusoid at the left. The endothelial wall of the branches (below) is continuous at various places with the outlying reticulum. In these regions the blood-vessel lumen becomes continuous with the intercellular spaces of the reticular stroma. Above, at the right, the injected ink has passed into the mouth of an open connection between the sinusoid and the reticular stroma, and at the left it has completely encircled a fat-cell. The sinusoid contains many erythrocytes and lymphocytes. × 300.

10 Another area from the same femur. Here the India ink has filled the space between a fat-cell and the supporting reticular stroma, and has even passed for a short distance beyond this space. × 300.

11 The blood vessel appears at the right. The endothelium is continuous with the reticulum above. The injected India ink occurs as irregular masses within the intercellular spaces of the reticular stroma. The same spaces contain also hemocytoblasts (lymphocytes) and erythrocytes. × 500.

12 The India ink in this area has passed into the reticular space surrounding a fat-cell. The ink mass has a sharp contour next the fat-cell; peripherally, the outline is very irregular. The nearest blood vessel lies some distance below the ink mass. × 300.

13 Drawing of a partially injected venous sinusoid. Here the India ink outlines a perilipocellular space continuous with the lumen of the sinusoid. This vessel contains many lymphocytes peripherally disposed. × 300.

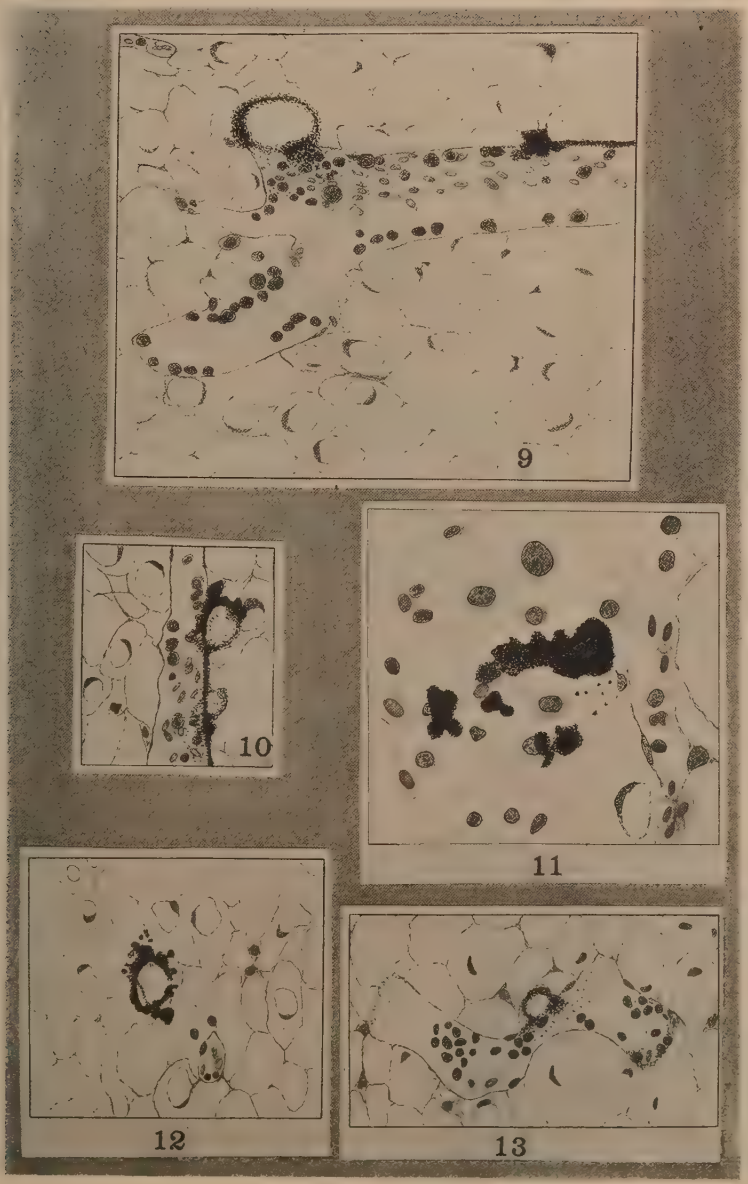
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PLATE 4

EXPLANATION OF FIGURES

14 Peripheral portion of hypoplastic femoral marrow. Diaphyseal bone appears at the right. To the left of the open space (a fixation artifact) occurs a sinus, here containing a few hemocytoblasts. Its left border is in part outlined by an irregular elongate mass of ink. A blood vessel is shown just below this mass. In specimens showing a more complete injection of India ink, the peripheral sinus (or hemocytopoietic area) may become completely filled, and ink may even pass into the lacunae of the adjacent bone. This peripheral more cellular and granulocytopoietically active area (sinus) is apparently in direct open communication with peripheral blood vessels and intercellular reticular spaces. × 300.

15 Similar area, showing an irregular ink mass within the meshes of the peripheral hemopoietic area. A blood vessel (capillary) appears in the lower left area. × 300.

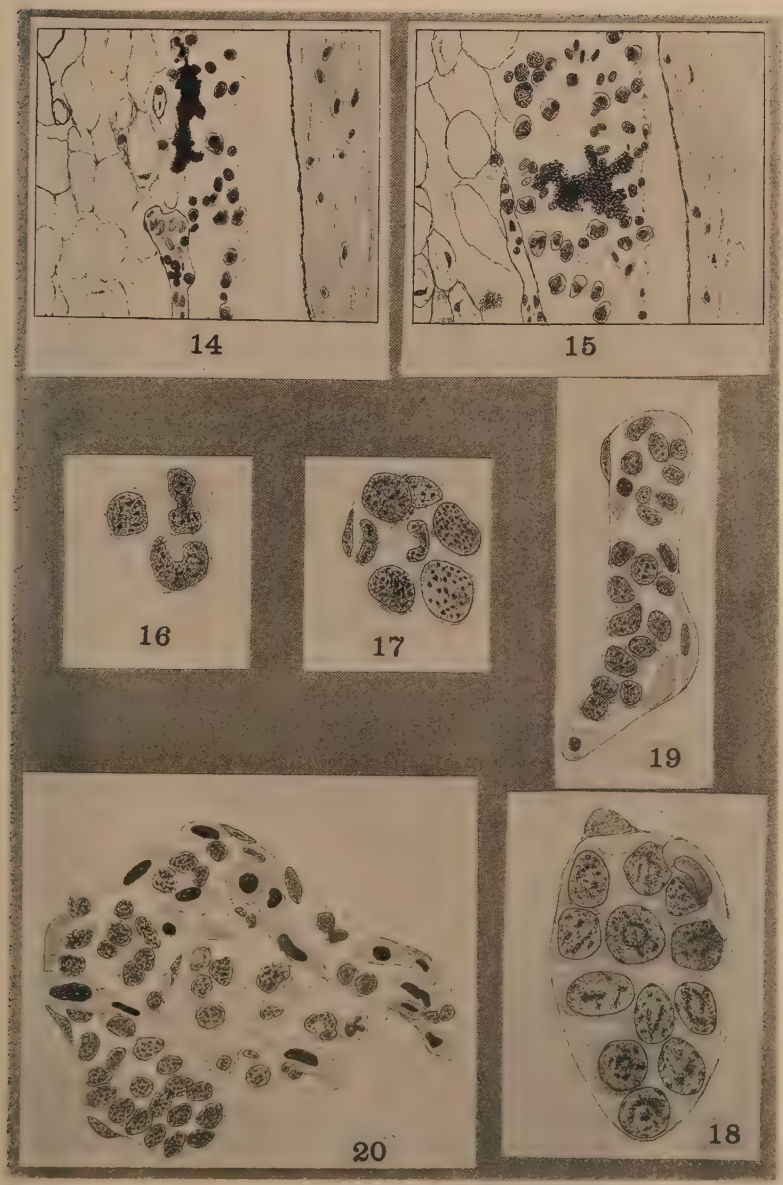
16 Group of three hemocytoblasts (erythroblasts) from the hyperplastic marrow shown in figure 3. These three cells constitute a small blood island. The two cells at the right, with bilobed nuclei, represent transition stages between reticulum cells and the lymphocyte at the left. A strand of reticulum is shown below. Giemsa stain. × 2300.

17 Larger group of hemocytoblasts from the same preparation. Two of the cells, at the right, are in early prophase. At the left is shown a reticulum cell in process of conversion into endothelium. × 2300.

18 Drawing of slightly later stage of stromal blood island from the same preparation. The two peripheral erythrocytes probably represent invasions from an adjacent sinusoid. × 2300.

19 Intermediate stage in the conversion of a stromal blood island into a venous sinusoid. × 1500.

20 Late stage in the same process. Below at the left the appearance is still that of a blood island of hemoblasts enveloped by reticulo-endothelium. Beyond this region appear stages in the differentiation of lymphocytes into erythrocytes, and the area has the appearance of a definitive venous sinusoid. In the bend of the sinusoid is shown the adjacent reticular stroma, containing erythrocytes. lymphocytes, and granulocytoblasts. × 1500.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ON CERTAIN MUSCLE ANOMALIES OF THE LOWER EXTREMITY

HENRY K. SEELAUS

The Laboratories of the Daniel Baugh Institute of Anatomy, Jefferson Medical College

TWO FIGURES

AN ANOMALOUS DIGASTRIC MUSCLE OF THE THIGH

In the course of the dissection of the thigh and gluteal region of an adult white male, there was discovered on the right side a separate muscle (fig. 1, *A*), 6.25 cm. long, passing through the greater sciatic foramen (foramen ischiadicus majus), inferior to the piriformis muscle, but separated from it by a well-defined interval. The posterior femoral cutaneous nerve was superficial to the muscle and the inferior gluteal artery and sciatic nerve (n. ischiadicus) were deep to it. The muscle ended in a tendon (fig. 1, *B*), 14 cm. in length, which crossed the long pudendal nerve lateral to the tuberosity of the ischium and entered the thigh lateral to the ischial head of the biceps femoris muscle. The tendon continued in this relation until it reached the middle of the thigh, where a second muscular belly (fig. 1, *C*), 9 cm. long, was developed which, in turn, ended in a small tendon (fig. 1, *D*), 2 cm. long, by merging with the long head of the biceps femoris at the junction of the middle and lower thirds of the thigh. Tracing the first muscular belly into the pelvis, it was found to arise from the ventral surface of the fourth sacral vertebra and the margin of the fourth sacral foramen. The nerve supply of the femoral belly was a small branch from the tibial side of the sciatic nerve, but, unfortunately, the innervation of the pelvic muscle was not determined.

This anomalous muscle appears to be of rare occurrence. The only instance in the literature that I could find was that reported by Paul H. Stevenson in 1922. The muscle of this communication differed somewhat from that described by Stevenson in that the tendon was not incorporated or associated with the capsule of the bursa lying between the gluteus maximus muscle and the great trochanter and in relation to the sciatic nerve.

The embryology of the anomalous muscle is not definitely determined. Stevenson considers two possibilities. First, that there are two aberrant muscle slips arising from two well-defined muscle entities; viz., the biceps femoris and the piriformis, known, in each case, not infrequently to give rise to supernumerary slips, whose tendons secondarily become associated with each other in the connective tissue overlying the greater trochanter. Secondly, that there is a single developmental anomaly resulting in a compound muscle of digastric form.

I am inclined to think that the anomaly reported in this paper belongs to the second possibility mentioned. Stevenson believes that "in the still undifferentiated myogenous zone of the limb bud up to the 7 or 10 mm. stage those concentrating areas of cells which are destined to differentiate later as to the specific anlages of the biceps and piriformis muscles lie very close together. The only structure intervening in the following stages of progressive differentiation in this region is the outgrowing sciatic nerve trunk. This means that in those cases where the sciatic nerve, either as a whole or in part, pierces the piriformis muscle, a portion of the anlage of this muscle is still less definitely separated from that of the biceps which lies immediately adjacent. Such a split-off portion of the piriformis anlage, as mentioned above, almost invariably again associates itself with the main body of the muscle to become incorporated in the common tendon of insertion, after transmitting a portion or all of the sciatic nerve through the proximal hiatus. Failure to reunite with its parent anlage, however, would present the alternative

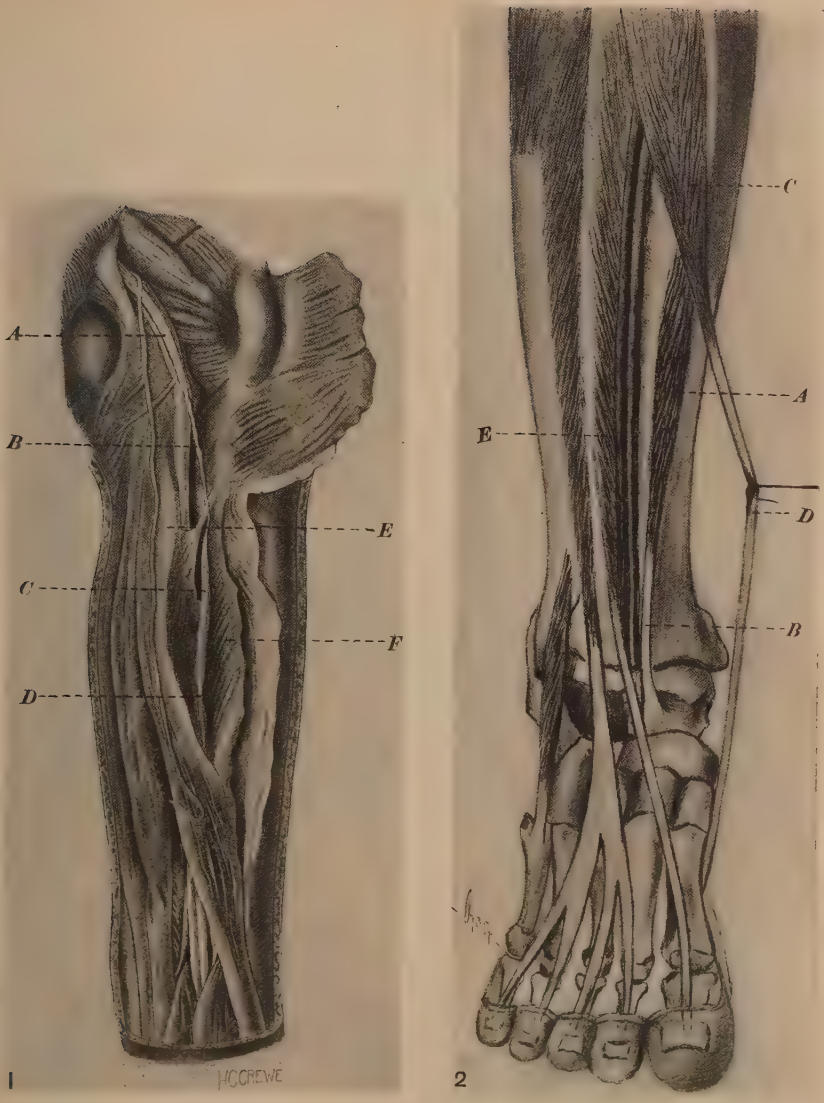

Fig. 1 Drawing of dorsal aspect of thigh, showing anomalous digastric muscle. *A*, pelvic belly of the anomalous muscle; *B*, tendon of pelvic belly; *C*, second muscular belly; *D*, tendon of insertion; *E*, ischial half of biceps femoris muscle; *F*, femoral half of biceps f. muscle.

Fig. 2 Drawing of tibio-astragalus anticus muscle (Gruber). *A*, muscular portion of anomalous muscle; *B*, tendon of insertion; *C*, tibialis anticus muscle; *D*, tendon of tibialis anticus muscle; *E*, extensor hallucis longus muscle.

possibilities, either of an independent existence or of an association with a neighboring muscle anlage.'' I believe that the present anomaly represents an example of such an association between the separated portion of the piriformis anlage and that of the biceps femoris.

A TIBIO-ASTRAGALUS ANTICUS MUSCLE

Several observers have encountered muscles somewhat similar to the second one that I report in this paper. Bahnsen, in 1868, described a tibialis anticus accessorium s. profundis. It had its origin from the lateral surface of the tiba alongside the tibial crest and was inserted into the cruciate ligament. Gruber noted three instances of a muscle named by him the tibio-astragalus anticus, which had its origin from the lateral surface of the tibia and the interosseous ligament and was inserted in the lateral side of the neck of the talus (astragalus). Two of the three muscles reported by Gruber had additional attachments to the medial (internal) malleolus through the medium of a retinaculum, and in one cadaver there was a double tendon, one inserting into the capsule of the talonavicular joint and the os naviculare, and the other into the neck of the talus. Wood noted a slip of tendon detached from the outer border of the tibialis anticus muscle to be implanted into the inner border of the cruciate (annular) ligament and dorsal fascia. Testut mentions attachments to the first phalanx of the great toe; to the anterior ligament of the tarsus and the aponeurosis of the dorsum of the foot; to the talus and the calcaneus; to the neck of the talus and the anterior part of the tibiotarsal synovia; to the plantar aponeurosis. Macalister, mentioned by LeDouble, noted a double tendon of the tibialis anticus muscle, one of which attached itself to the navicular and the first cuneiform bone and the other to the talus, the calcaneus and the dorsal fascia of the foot. Hyrtl, also quoted by LeDouble, describes a fascicle from the deep surface of the tibialis anticus muscle, to the neck of the talus and to the capsule of the articulation of the instep (cou-de-pied).

The muscle here described was found in the right leg of an adult colored man. Its origin was from the anterior surface of the lower third of the tibia lateral to the prominent anterior tibial crest. It was a fairly good-sized muscle (fig. 2, *A*), being 9 cm. long. A large part of the muscular belly was attached to the interosseous membrane and to an intermuscular septum intervening between it and the tibialis anticus muscle (fig. 2, *C*), which was its lateral muscular relation. The anomalous muscle ended in a well-defined tendon (fig. 2, *B*), at a point 3.5 cm. above the articular end of the tibia, which tendon was first medial and then passed deep to the tendon of the tibialis anticus muscle and the transverse ligament. The tendon of insertion traversed the same mucous compartment as the tendon of the tibialis anticus and, after piercing the capsule of the ankle-joint, was inserted in a fan-like manner into the anterosuperior portion of the head of the talus. The deep peroneal nerve and the anterior tibial artery and vein were prominent lateral relations. Passing close to the tendon of insertion, in addition to the tendon of the tibialis anticus muscle, was the tendon of the long extensor of the great toe (m. extensor hallucis longus). The nerve supply was a branch of the deep peroneal nerve which was given off just distal to the point from which the tibialis anticus muscle received its supply.

The embryology of this muscle is even less evident than that of the digastric muscle reported elsewhere. In a 14-mm. embryo the various muscle groups of the anterior portion of the leg are fairly well differentiated, the muscular anlage of the tibialis anticus being definitely established, while the tendons of the extensor digitorum longus and the extensor hallucis longus are represented by a sheet of tissue in which the segmentation is just beginning (Bardeen). The metatarsal bones become well differentiated before the tarsals (Shomburg, Bardeen). The first differentiation of definite bones of the tarsus occurs toward the end of the fifth week and is manifested by a condensation of tissue in specific areas. After the tarsal elements have become well established, the

talus has somewhat the form of a rhomboid plate which runs dorsally from the fibular side toward the tibial side on the plantar surface. In an embryo of 20 mm. the most notable tarsal change will be seen in the talus (Bardeen). It has become considerably thickened, extends farther than the calcaneus, and, between the tibia and navicular, has so increased in size that the foot is bent toward the fibular side. While the embryo is growing from 20 to 30 mm., the talus develops a well-marked articular process toward the tibia and fibula, two characteristic articular surfaces toward the calcaneus, and distally it sends forth a rounded process to articulate with the navicular.

It is evident that the talus developed prominently and conspicuously at this early time, and when we take into consideration the fact that the foot is convex on its dorsal surface, it seems reasonable to suppose that the talus is the bone most likely to present itself for attachment for any separated myogenous cells which may come from the muscle anlage of the tibialis anticus.

I believe that the muscle in question is a derivative of the tibialis anticus muscle because, 1) it passed through the same mucous compartment as the tibialis anticus muscle; 2) it took an origin from the same side of the tibia as its parent muscle, albeit its origin was more distal than the normal origin of the tibialis anticus; 3) of all the muscles of the ventral leg, the tibialis anticus was nearest to the prominently developing talus and, therefore, a separated portion of the tibialis anticus was most apt to become attached to the talus, and, 4) its nerve supply was derived from the same side and same region of the deep peroneal nerve as the nerve supply of the tibialis anticus muscle.

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THE MUSCULATURE OF THE SUPERIOR EXTREMITY OF THE ORANG-UTAN, SIMIA SATYRUS

WALTER E. SULLIVAN AND CARROL W. OSGOOD
University of Wisconsin

ELEVEN FIGURES

While several excellent papers have been written on the musculature of the orang-utan, we feel that a detailed description of another animal is well worth while. Some of the earlier papers have been of particular assistance to us, and we wish to express our indebtedness to Bryce, Chapman, Fick, Hepburn, Pira, Primrose, and Sonntag. While Sonntag's work is usually not at all in detail, he has rendered an invaluable service in bringing together much of our knowledge of the anthropoids and in compiling relatively complete bibliographies.

We discuss the musculature in some detail, for we feel that final analyses and comparisons to be of any value must be based on detailed information.

The specimen was a young animal from the local zoo. Its age was estimated as four or five years. The roentgenograms of the hand and elbow (figs. 1 and 2) give some idea of its physiological age.

The data on the length of the various bones give a basis for estimating some of the mechanical factors as well as additional evidence of the physiological age. The data are in millimeters: clavicle, 100; scapula, 90; width, 65; humerus, 218; radius, 220; ulna, 222; carpus, 24. The figures for the metacarpals and phalanges are indicated in the table following.

	I mm.	II mm.	III mm.	IV mm.	V mm.
Metacarpal	32	67	68	63	58
Proximal phalanx	18	48	52	50	42
Intermediate phalanx		27	35	33	25
Distal phalanx	11	16	16	15	15
Total	61	158	171	161	140

In any grouping of muscles there are several factors, especially position, function, development, and innervation,

to be kept in mind. We have tried to group them on the basis of function and at the same time to keep the other factors before us. While the result is not entirely satisfactory, the arrangement is fairly convenient.

With the thought in mind that the orang-utan uses his superior extremities about equally for motion and locomotion, we have used the terms proximal and distal attachments instead of origin and insertion. In the discussion of the function of the muscles, observations on two living animals are included.

The grouping followed is listed below.

Muscles of the shoulder-girdle

The superficial muscles:
- M. trapezius
- M. sternocleidomastoideus

The deep muscles:
- M. omo-occipitalis
- M. rhomboideus
- M. omocervicalis
- M. levator scapulae
- M. serratus anterior
- M. pectoralis minor
- M. subclavius
- Ligamentum costocoracoideum
- Membrana costocoracoidea

Muscles of the shoulder-joint

The long muscles:
- M. pectoralis major
- M. latissimus dorsi
- M. latissimo-condyloideus

The short muscles:
- M. deltoideus
- M. supraspinatus
- M. infraspinatus
- M. teres major
- M. teres minor
- M. subscapularis
- M. coracobrachialis

Muscles of the arm

The dorsal muscles:
- M. triceps
- M. anconeus

The ventral muscles:
- M. biceps
- M. brachialis

Muscles of the forearm and the antibrachial fascia

Fascia antibrachii

The radiodorsal muscles:
- A flexor of the elbow:
  - M. brachioradialis
- The extensors of the wrist:
  - M. extensor carpi radialis longus
  - M. extensor carpi radialis brevis
  - M. extensor carpi ulnaris
- The extensor of the digits:
  - M. extensor digitorum longus
  - M. extensor digitorum brevis
- The supinator muscle:
  - M. supinator
- The long muscles of the thumb:
  - M. extensor pollicis
  - M. abductor pollicis longus

The ulnovolar group:
- The pronators:
  - M. pronator teres
  - M. pronator quadratus
- The flexors of the wrist:
  - M. flexor carpi radialis
  - M. flexor carpi ulnaris
  - M. palmaris longus
- The flexors of the digits:
  - M. flexor digitorum sublimis
  - M. flexor digitorum profundus

Muscles of the hand

The short muscles of the thumb:
- M. abductor pollicis brevis
- M. flexor pollicis brevis
- M. opponens pollicis
- M. adductor pollicis

The short muscles of the fifth digit:
- M. abductor digiti quinti
- M. flexor digiti quinti
- M. opponens digiti quinti

The short palmar muscle
The lumbrical muscles
The interosseous muscles

THE MUSCLES OF THE SHOULDER-GIRDLE

We have designated as muscles of the shoulder-girdle those that connect it with the axial skeleton and have their primary action on either the sternoclavicular or acromioclavicular joint. Two of the muscles, the omo-occipital and the omocervical, occur but rarely in man.

It is convenient to divide these muscles into a superficial and a deep group.

The mm. trapezius and sternocleidomastoideus form the superficial musculature. The latter has to do principally with movements of the head and neck, but its development and general morphology make it desirable to group it with the m. trapezius.

The m. trapezius passes from the superior nuchal line, external occipital protuberance, and the spinous processes of the cervical and thoracic vertebrae to the spine and acromion of the scapula and the lateral portion of the clavicle. The m. sternocleidomastoideus has one attachment to the mastoid process and superior nuchal line and the other to the sternum and clavicle. The muscle on one side showed a marked variation in its cranial attachment. The literature indicates that this muscle is rather unstable in the anthropoids.

As deep muscles of the shoulder-girdle are grouped the mm. omo-occipitalis, rhomboidei, omocervicalis, levator scapulae, serratus anterior, pectoralis minor and subclavius. Of these, the mm. omo-occipitalis, rhomboidei, levator scapulae, and serratus anterior form one natural morphological group. The m. pectoralis minor develops with the pectoralis major from the pectoral premuscle mass. Lewis describes the m. subclavius as developing in situ from the mesenchyme of the

cervical region. The morphology of the m. omocervicalis is not clear. Bryce states in his discussion of the anomalous muscles of the neck of man that it is supplied by the third or fourth cervical nerve, and possibly represents material from the myotomes of these segments normally suppressed or incorporated in the m. trapezius.

These muscles, with the exception of the subclavian, have their distal attachments to the scapula. The proximal attachment of the m. omo-occipitalis is to the skull; of the rhomboidei to the vertebral spinous processes; of the levator scapulae to the vertebral transverse processes; of the mm. serratus anterior and pectoralis minor to the ribs. The m. omocervicalis passes from the transverse process of the atlas to the clavicle; the subclavius from the first rib.

M. trapezius (figs. 3, 4, 7)

The m. trapezius is a broad, flat, subtriangular structure covering the dorsum of the neck and the dorsum of the thorax in its upper part. In general, it appears quite like the human muscle, but a careful examination shows marked differences. Its greater thickness in the orang-utan indicates that it is more powerful. The aponeurotic area opposite the lower cervical and upper thoracic spines, so characteristic of the human muscle, is entirely absent from the orang-utan. The aponeurotic area is confined to a region over the medial end of the spine and the upper part of the infraspinous fossa.

The cranial fibers are short, and this is to be correlated with the length of the neck, but cannot be held as the cause of it, as suggested by Primrose.

The proximal attachment is fleshy along the medial half of the superior nuchal line (for a distance of nearly 4 cm. from the external occipital protuberance), the 'ligamentum nuchae' (this is probably not a true ligamentum nuchae), the spinous processes of the two lower cervical, of all the thoracic, and of the first lumbar vertebrae. Primrose gives no lumbar attachment. Toward its caudal end there is some fusion with the cephalic end of the m. latissimus dorsi which it overlies.

For their distal attachment the cranial fibers pass caudad, laterad, and ventrad to the lateral third of the clavicle. The upper cervical fibers have a similar direction, while the lower cervical fibers in correlation with the short neck and high shoulders are horizontal. The thoracic fibers pass cephalad and laterad, the obliquity of the fibers increasing from cephalad to caudad. The most caudal bundles attach to the aponeurotic fascia over the infraspinous muscle. The distal attachment as a whole is to the lateral third of the clavicle, to the acromion, to the spine of the scapula, except an area at its medial end near the base, and to the infraspinous fascia.

M. sternocleidomastoideus (figs. 5, 6)

The sternocleidomastoid muscle crosses the side of the neck obliquely from the mastoid region and adjacent parts of the skull to the ventral surface of the sternum and the medial end of the clavicle. It is well developed and lies relatively superficial, though covered by the platysma and the laryngeal air sacs. At its cranial attachment it is in contact with the trapezius, but at its clavicular end widely separated from the latter by an interval equivalent to three-fourths the length of the clavicle. The result is that the posterior triangle of the neck has a long anterior border formed by the sternocleidomastoid, a long inferior border about equal in length to the anterior and formed by the clavicle, and a short posterior border about half the length of either of the other borders. Toward the lateral end of the clavicle the omocervical muscle is attached in the interspace between the mm. sternocleidomastoideus and trapezius.

The distal attachment may be separated into three parts. There is, first, a heavy tendon attached to the ventral surface of the manubrium sterni down as far as the plane of the second costal cartilage. This tendon passes ventral to the sternal portion of the m. pectoralis major. There is next a flat fibrous segment attached to the cranial margin of the sternum and to the capsule of the sternoclavicular joint. This is very closely bound up with the part first described, but lies

dorsal to it and to the sternal portion of the greater pectoral muscle. These two portions go over into a heavy fleshy belly which forms the ventral and greater part of the muscle ($\frac{3}{4}$ to $\frac{5}{6}$). There is, finally, a small rounded tendon about 1 mm. in diameter which expands to gain attachment to the ventral surface of the medial end of the clavicle and to the capsule of the sternoclavicular joint. This tendon as it passes craniad goes over into the dorsal part of the muscle. The dorsal and ventral segments are usually described as being separable throughout their entire length, but in the specimen at hand they blend about the middle of the neck.

The proximal attachment is to the mastoid process and along the superior nuchal line for about 50 mm. On the right side it just reaches the m. trapezius; on the left, it overlaps the latter by 10 mm.

On the right side there is an additional attachment to the digastric muscle. This is a linear attachment to the postero-inferior margin of the tendon from the mandible dorsad and cephalad for a distance of 14 mm. The segment arising here passes downward as a thin slip to form the most ventral portion of the sternocleidomastoid. Opposite the posterior end of the part just described is a small fibrous band which passes cephalad from the main mass of the muscle deep to the m. digastricus.

On the left side a small tendinous cord connects the mm. sternocleidomastoideus and digastricus.

M. omo-occipitalis (fig. 3)

The omo-occipital is a long, flat, narrow muscle lying just deep to the m. trapezius. At its cephalic end it has a width of about 20 mm., then it gradually goes over into a narrow tendon about 1 mm. wide at the scapular attachment.

The proximal attachment, which is fleshy, is on the medial part of the superior nuchal line beginning a short distance from the external occipital protuberance. The distal end is attached by a narrow tendon to the vertebral margin of the scapula immediately below the medial angle.

The omo-occipital muscle is apparently quite variable. It is frequently so continuous with the rhomboid mass that it is described as a part of it. In our specimen it has attained complete independence, and we have described it as a separate muscle. Most workers agree that the rhomboid mass extends to the occipital bone in the orang-utan, though Fick did not find it so in his specimen.

Mm. rhomboidei (fig. 3)

The rhomboid mass is usually a continuous sheet without separation into minor and major portions. If we consider the m. omo-occipitalis a part of it, it would here represent an element that has attained complete independence. At the caudal end there is a small slip that is independent at its proximal attachment, but blended at its distal.

The proximal attachment is to the 'ligamentum nuchae' and the spinous processes from the plane of the second cervical to the plane of the seventh thoracic vertebra. The attachment is aponeurotic in its cephalic and caudal thirds, but fleshy in the middle third.

The distal attachment is to the vertebral margin of the scapula along the greater part of its length. It falls short of the medial angle by about 2 mm. and of the inferior by about 10 mm. The nature of the attachment reverses that of the proximal end. It is aponeurotic in the middle, but fleshy in its upper and lower parts.

There is a narrow caudal slip quite independent of the main mass. This has its proximal attachment to the dorsal layer of the lumbodorsal fascia and its distal to the vertebral margin of the scapula in continuity with the rhomboid.

M. omocervicalis (fig. 4)

The omocervical muscle may be described as ribbon-shaped, although it is much thicker than most muscles that fall in that group. It may be split into a dorsal and a ventral segment, but the separation is somewhat artificial. At its

proximal end it is between the mm. digastricus and levator scapulae. Toward the distal end the lateral margin is partially enveloped by the anteromedial margin of the m. trapezius.

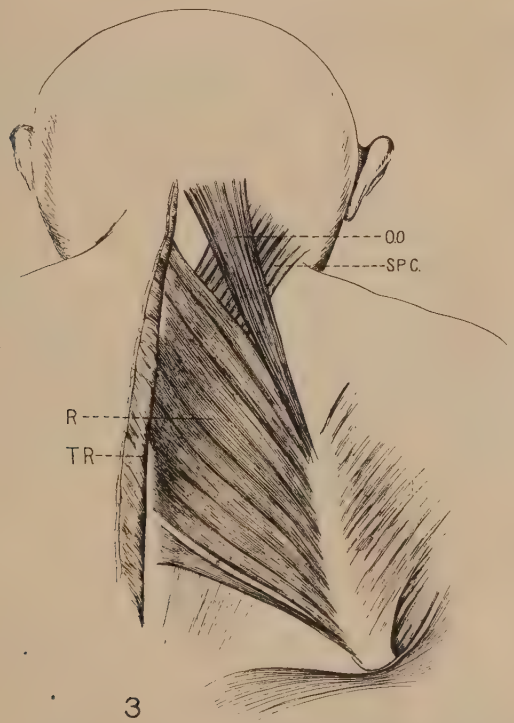


Fig. 3 A dorsal view of the deep muscles of the shoulder-girdle. The musculus trapezius is turned back. *O.O.*, m. omo-occipitalis; *R.*, m. rhomboideus; *Sp.C.*, m. splenius capitis; *Tr.*, m. trapezius.

The proximal attachment of the muscle is to the transverse process of the atlas; the distal to the clavicle lateral to its middle.

The proximal attachment is apparently quite uniformly to the atlas, though it may come from the ventral arch as well as from the transverse process. The clavicular attachment seems fairly constant for the anthropoids, but in other pri-

mates it may pass to the acromion or spine of the scapula. Sonntag gives the distal end as attached to the acromion.

M. levator scapulae (fig. 4)

The levator of the scapula is an elongated muscle deeply placed in the back of the neck. At its proximal end it is dorsal to the mm. omocervicalis and iliocostalis cervicis and ventral to the splenius cervicis. The distal end of the muscle is overlaid medially and dorsally by the omo-occipital and the upper part of the rhomboid. It is flattened dorsoventrally and is wider at its proximal end than at its distal. It consists of four quite distinct slips.

The proximal attachment is by five small tendons to the transverse processes of the upper four cervical vertebrae, two slips coming from the third. The segments from the several vertebrae remain independent almost throughout the entire length of the muscle, but the two slips from the third soon fuse to form a single bundle. The distal attachment is to the medial angle of the scapula cranial to the rhomboid and omo-occipital muscles.

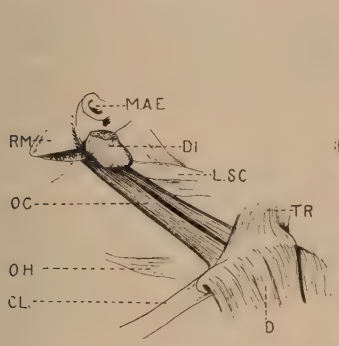
M. serratus anterior

This is a broad, flat, thin muscle covering the lateral thoracic wall. It is in part under cover of the pectoral muscles.

Proximally, it is attached by eleven fleshy digitations to the outer surfaces of the first eleven ribs toward their ventral ends. The bundle from the first rib is by far the heaviest and spreads out as it passes toward the scapula. The digitations from the first four ribs are overlaid by the lesser pectoral muscle; those from the fifth and sixth, by the greater pectoral. From the fifth to the eleventh ribs it interdigitates with the external oblique muscle of the abdominal wall.

The distal attachment is along the entire length of the vertebral margin of the scapula. The slip from the first rib radiates so as to be attached to the upper three-fourths of the margin, while the slips from the other ribs attach to the rest

of it and go over onto the inferior angle. The upper part of the muscle is 10 mm. wide at the first rib, but 60 mm. wide at the scapular end. The lower part of the muscle reverses this condition, being 143 mm. wide at its costal attachment, but only 32 mm. at the scapular. This interesting arrangement is very similar to the condition found in man. It serves to increase enormously the power of the muscle as a lateral rotator of the scapula.



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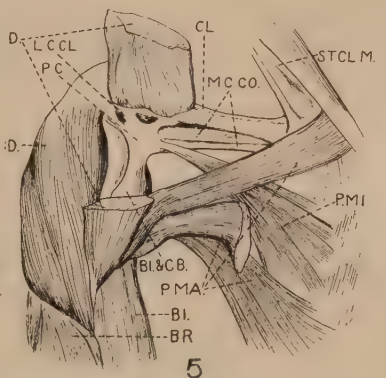

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Fig. 4 A ventral view of the deep muscles of the shoulder-girdle. *Cl.*, clavicula; *D.*, m. deltoideus; *Di.*, m. digastricus; *L.Sc.*, m. levator scapulae; *M.A.E.*, meatus acusticus externus; *O.C.*, m. omocervicalis; *O.H.*, m. omohyoideus; *R.M.*, ramus mandibulae; *Tr.*, m. trapezius.

Fig. 5 A ventral view of the structures attached to the coracoid process. *Bi.*, m. biceps; *Br.*, m. brachialis; *C.B.*, m. coracobrachialis; *Cl.*, clavicula; *D.*, m. deltoideus; *M.C-co.*, membrana costocoracoidea; *L.C-cl.*, ligamentum coracoclaviculare; *L.C-co.*, ligamentum costocoracoideum; *P.C.*, processus coracoideus; *P.Ma.*, m. pectoralis major; *P.Mi.*, m. pectoralis minor; *St.Cl.M.*, sternocleidomastoideus.

Occasionally the mm. levator scapulae and serratus anterior are in continuity both at the proximal and distal attachments. This is, however, a relatively rare condition in man and the anthropoids.

M. pectoralis minor (fig. 5)

The lesser pectoral muscle has the usual position under cover of the greater. Its general shape is triangular. At the

proximal end it is flat and thin, but distally it goes over gradually into a small round tendon.

The proximal attachment is to the ventral ends of the third, fourth, and fifth ribs, to the adjacent portions of the costal cartilages, and to the fascia of the intervening intercostal muscles.

It is attached distally to the tip and medial surface of the coracoid process of the scapula in common with the costocoracoid ligament and is in part continuous with the medial portion of the latter. Primrose found its distal end continuous with the trapezoid portion of the coracoclavicular ligament and with the coraco-acromial.

M. subclavius

The subclavian muscle is a small bundle passing from the first costal cartilage to the caudal surface of the clavicle. It is attached to the cartilage about 5 mm. medial to the costochondral junction.

Ligamentum costocoracoideum (fig. 5)

The ligament in the animal at hand is entirely chondrocoracoid. It passes from the capsule of the sternoclavicular joint and from the first costal cartilage to the medial surface of the coracoid process near its tip. Its attachment to the cartilage is medial to that of the subclavian muscle. It is a little more than 2 mm. in diameter. Before reaching the coracoid process it blends with and partially encapsulates the tendon of the lesser pectoral muscle.

Membrana costocoracoidea

There is a heavy membrane, the inferior margin of which is attached to the costocoracoid ligament. Its clavicular margin is thickened in its lateral half.

THE MUSCLES OF THE SHOULDER-JOINT

In this group are included the muscles that have their primary, in most cases their only, action on the shoulder-joint.

It is convenient to recognize a group of long muscles and a group of short ones.

The long group includes the mm. pectoralis major, a ventral muscle, and the latissimus dorsi and latissimo-condyloideus, dorsal muscles. Of these the first two act on the sternoclavicular and acromioclavicular joints as well as on the shoulder-joint. The greater pectoral muscle runs from the sternum, costal cartilages, and abdominal aponeurosis to the upper part of the humerus. The m. latissimus dorsi has its proximal attachment to the lumbar and sacral vertebrae and the iliac crest; the distal to the upper part of the humerus. Sonntag gives a costal attachment. The m. latissimocondyloideus has one end attached to the latissimus dorsi near its humeral end, the other to the distal part of the humerus. This, in many ways, is the most interesting muscle of the group. It is present in many of the primates below man and is usually thought of as a climbing muscle, though not necessarily associated with arboreal forms. It is occasionally found in man.

The short muscles pass from the shoulder-girdle to the humerus. Here are grouped the mm. supraspinatus, infraspinatus, teres major, teres minor, subscapularis, and coracobrachialis. With the exception of the coracobrachial, these are dorsal muscles.

The coracobrachial muscle is usually put with the ventral muscles of the arm, because of its probable development from the same mass. On any other basis it may better go with the muscles of the shoulder.

M. pectoralis major (figs. 5, 6)

The greater pectoral muscle covers a large part of the anterior thoracic wall. In the orang-utan it is in three distinct segments—a manubrial, a sternochondral, and a costo-abdominal. The clavicular portion is wanting, as is often, perhaps usually, the case.

The manubrial segment has its proximal attachment to the ventral surface of the manubrium, to the capsule of the sternoclavicular joint, and to a slight degree to the second

costal cartilage. The two sternocleidomastoid muscles are attached to the ventral surface of the sternum between the two major pectorals, so that the latter do not approach each other in the midline.

The distal attachment is to the upper third of the shaft of the humerus along the crest of the greater tubercle. Here it is ventral to the other portions.

This manubrial segment maintains approximately a uniform size throughout, though it is somewhat flattened at its proximal end, subcylindrical near its middle, and distinctly flattened at its distal end. It is twisted so that the fibers which are ventral at the proximal end become caudal at the distal; the fibers which are dorsal at the proximal end become cephalic at the distal. At its sternal attachment it separates the sternal and clavicular portions of the sternocleidomastoid muscle.

The sternochondral portion is attached proximally to the ventral surface of the fifth, sixth, and seventh costal cartilages and adjacent segments of the sternum.

The distal attachment is through an aponeurosis to the humerus just dorsal to that of the manubrial segment. This segment is much wider at its costosternal end (57 mm.) than at the humeral (17 mm.).

The fiber bundles here are also twisted, so that in passing from proximal to distal the more cranial fibers become ventral and distal and the more caudal become dorsal and cranial. The general direction of this segment is horizontal.

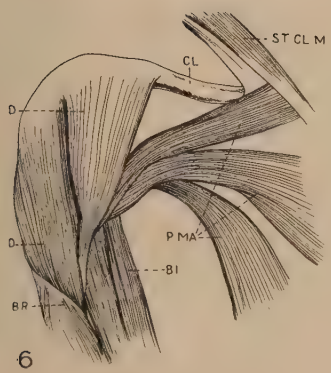
The costo-abdominal portion passes from the ventral ends of the fifth and sixth ribs and the aponeurosis of the external oblique muscle to the crest of the greater tubercle. Here it attaches proximal to the sternochondral part and dorsal to the manubrial. It extends craniad as far as the greater tubercle and capsule of the shoulder-joint.

This segment is also twisted on itself. Its general direction approaches the vertical.

M. latissimus dorsi (fig. 7)

This is a broad flat muscle covering the dorsal and lateral areas of the lumbar region, the lower part of the dorsal and a good part of the lateral thoracic regions.

The proximal attachment is through an aponeurosis, the lumbodorsal fascia, to the spines of the tenth, eleventh, and



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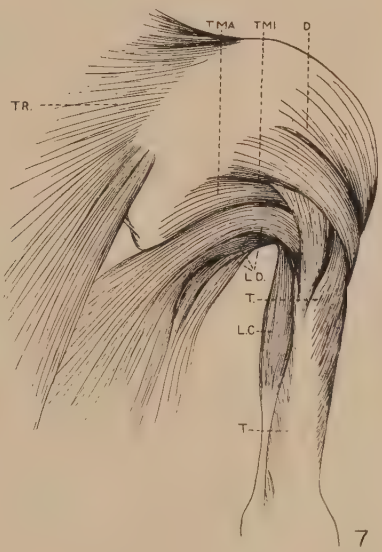

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Fig. 6 The superficial musculature of the pectoral and shoulder regions. *Bi.*, m. biceps; *Br.*, m. brachialis; *Cl.*, clavicula; *D.*, m. deltoideus; *P.Ma.*, m. pectoralis major; *St.Cl.M.*, m. sternocleidomastoideus.

Fig. 7 A dorsal view of the shoulder and arm, primarily to show the m. latissimo-condyloideus. *D.*, m. deltoideus; *L.C.*, m. latissimo-condyloideus; *L.D.*, m. latissimus dorsi; *T.*, m. triceps; *T.Ma.*, m. teres major; *T.Mi.*, m. teres minor; *Tr.*, m. trapezius.

twelfth thoracic vertebrae, the lumbar and sacral vertebrae, and the dorsal third of the iliac crest. It has a fleshy attachment to the anterior two-thirds of the crest. The aponeurotic portions of the two muscles form a diamond-shaped area comparable to that found in man. We found no scapular or costal attachments, but Sonntag found the latter present.

At its cephalic end where it is covered by the m. trapezius it fuses with that muscle.

Distally, it is attached to the humerus by two slips. The cephalic fourth is inserted with the m. teres major to the distal part of the crest of the lesser tubercle. These two muscles are closely blended in a common tendon, of which the latissimus forms the distal part. The caudal three-fourths goes over into a tendon that attaches to the intertubercular sulcus, ventral and in part cephalad to the tendon of the cephalic fourth. The fibers of the caudal segment are twisted just before reaching the humerus, so that those from the iliac crest insert higher than those from the lumbar region.

M. latissimo-condyloideus (*M. dorso-epitrochlearis*) (fig. 7)

This may be considered separately or as a part of the m. latissimus dorsi. Its innervation from the radial nerve would indicate that it may be a separate muscle.

Its proximal attachment is to the ventral tendon of the m. latissimus dorsi, perhaps largely to its ventral surface. The distal attachment is to the medial epicondyle of the humerus and to the line above it. Its distal third is aponeurotic. Hepburn comments that the muscle never reaches the medial epicondyle, but ends in the intermuscular septum. In the specimen at hand one could make that interpretation, but he would have to add that the free edge of the septum is thickened to form a cord attached to the epicondyle.

M. deltoideus (figs. 4, 5, 6, 7)

The deltoid is a heavy triangular muscle covering the lateral surface of the shoulder. At its proximal end it is somewhat separable into three parts—a ventral fourth (clavicular), a middle two-fourths (acromial and spinous), and a dorsal fourth (spinous and infraspinous). The first part overlaps the second.

The proximal attachment is to the lateral half of the clavicle, to the acromion, to the scapular spine in its lateral part, and to the infraspinous aponeurotic fascia nearly to the vertebral margin.

Distally, it is attached to the lateral surface of the shaft of the humerus a little above its middle. Mivart notes that there is usually no deltoid tubercle.

M. supraspinatus

The supraspinous muscle is well developed and completely fills its fossa. Proximally, it is attached to the superior scapular border from the scapular notch to the medial angle, then along the vertebral border to the base of the spine, from the upper surface of the spine as far as the acromion, and from the medial third of the supraspinous fossa. It passes deep to the acromion to take its distal attachment on the superior part of the greater tuberosity of the humerus. It has but a loose attachment to the capsule of the shoulder-joint. Toward the distal end it blends with the infraspinous muscle.

M. infraspinatus

The infraspinous muscle practically fills its fossa. It is covered for a small area in its medial part by the m. trapezius and in its lateral part by the m. deltoideus. The proximal attachment is from the greater part of the infraspinous fossa, from the infraspinous fascia and from the inferior surface of the spine, except in its lateral part. Along its lateral margin the muscle is closely associated with the mm. teres major and minor.

Distally, it is attached by means of a short flat tendon into the greater tuberosity of the humerus between the insertions of the supraspinous and lesser teres muscles. There is a small slip which may be considered the deepest portion of the muscle attached to the axillary border in common with the m. teres minor. This passes laterad to lie in contact with the capsule of the joint.

M. teres major (fig. 7)

The greater teres is a heavy rounded muscle along the axillary border of the scapula. In its medial two-thirds it

is superficial, but laterally it is covered dorsally by the long head of the m. triceps.

Proximally, it is attached through fleshy bundles to the inferior third of the axillary margin and the adjacent part of the dorsal surface of the scapula. Here it is somewhat blended with the infraspinous muscle and more intimately with the subscapular.

The distal attachment is by a heavy flat tendon to the dorsal border of the intertubercular groove of the humerus. Here it is joined by a slip from the m. latissimus dorsi as described under the latter.

M. teres minor (fig. 7)

The m. teres minor lies just below and parallel to the infraspinatus. It has its scapular attachment to the upper two-thirds of the axillary margin dorsal to the attachment of the long head of the triceps and extending from the m. teres major to the neck of the bone. The humeral insertion is through a short flat tendon to the dorsal portion of the greater tuberosity. Toward the inferior part of its attachment it lies between the deltoid and infraspinous muscles, but for the most part it lies between the latter and the long head of the triceps. The triceps separates it from the m. teres major.

M. subscapularis

This is a thick fleshy muscle filling the greater part of the subscapular fossa. It may be partially divided into a number of bundles more or less blended medially, but more separable laterally. A small upper bundle is quite independent of the rest of the muscle. For the most part the upper bundles overlap the lower ones. The muscle is relatively thin at its upper margin, but thick and rounded toward the lower. The costal surface becomes aponeurotic, especially in its lateral part.

The proximal attachment is to the subscapular fossa as far laterad as the plane of the coracoid process. Along its axillary margin near the inferior angle it is blended with

the m. teres major. The humeral attachment is fleshy and fibrous to the lesser tubercle. Here it is crossed by the coracobrachial muscle and the short head of the biceps.

M. coracobrachialis

This is a long rounded muscle along the medial side of the arm in its upper half. It may be divided into a dorsal and a ventral segment between which passes the musculocutaneous nerve. These represent the mm. coracobrachiales medius and longus of some authors. The latter has been described as having an attachment through the intermuscular septum as far as the medial epicondyle.

The scapular attachment is to the coracoid process. This is largely fleshy, though fibrous ventrally and laterally where it is very closely blended with the short head of the m. biceps. The humeral attachment is both fleshy and fibrous to the medial surface of the shaft about its middle.

THE MUSCLES OF THE ARM

The muscles of the arm which for the most part act on the elbow-joint fall into two natural groups, a dorsal and a ventral. The dorsal or extensor group includes the mm. triceps and anconeus; the ventral or flexor group, the brachialis and biceps.

The m. triceps runs from the scapula and humerus to the ulna; the anconeus, from the humerus to the ulna; the brachialis, from the humerus to the ulna; the biceps, from the scapula to the radius.

While these are primarily muscles of the elbow-joint, the m. triceps through its long head also acts on the shoulder-joint. The m. biceps acts on the shoulder-, elbow-, and radioulnar joints and is often grouped with the supinators.

In the specimen at hand the entire group is well developed. The m. biceps has no lacertus fibrosus. The m. anconeus is not easily separable from the triceps.

M. triceps (fig. 7)

The m. triceps is a heavy muscle covering the entire dorsal surface of the arm and with the long head especially large. The muscle is largely fleshy in its upper part, but the dorsal surface of the lower part is a heavy aponeurosis.

The long head has its scapular attachment to the upper half of the axillary margin. Here it is between the mm. teres major and teres minor. The lateral head has its proximal attachment to the dorsal surface of the shaft of the humerus from the surgical neck to the radial groove. It is under cover of the distal part of the deltoid muscle. The medial head begins a little below the surgical neck and covers the dorsal surface of the shaft medial to the radial sulcus and distal to it. In its distal half it is attached to the intermuscular septa.

The three heads have a distal attachment as a common mass to the dorsal surface of the olecranon of the ulna and to the adjacent antibrachial fascia.

M. anconeus

This is a small muscle not readily separated from the triceps. Its humeral attachment is to the lateral epicondyle; its ulnar on the dorsal surface of the shaft in its upper part and on the olecranon. It is also attached to the fascia which covers it.

M. biceps brachii

The biceps has its usual position on the front of the arm. The long head has its scapular attachment to the supraglenoid tubercle, the short head to the tip and inferior surface of the coracoid process. A few fibers are in continuity with the coraco-acromial ligament. The long head passes as a slender tendon through the capsule of the shoulder-joint, then through the intertubercular sulcus to become fleshy at about the plane of the surgical neck. The short head has a tendinous origin in common with the coracobrachial muscle

from the coracoid process. The ventral surface of this common mass is fibrous, and it is from this that the greater part of the biceps comes. It becomes fleshy at the same level as the long head.

The two heads pass down the front of the arm, readily separable from each other to a point a little above the elbow where they go over into a common flattened tendon which attaches to the proximal part of the medial surface of the radius dorsal to its radial tuberosity. In its proximal third the biceps is covered ventrally by the deltoid and greater pectoral muscles.

At the distal end there is no indication of a lacertus fibrosus. From the work of others, this would seem to be the usual condition, though Primrose has described a well-developed bicipital fascia.

M. brachialis

The brachial is the thickest and heaviest muscle of the arm, exceeding even the triceps in transverse area. It covers the distal two-thirds of the ventral surface of the humerus distal to the attachment of the deltoid. It is largely fleshy, but becomes fibrous toward its distal end, especially in its middle part. It is at first dorsal to the biceps, but comes to lie in part medial to the latter. At the proximal end it is blended with the deltoid muscle, which it in part encloses.

Toward the distal end it would seem to consist of three parts—a central part made up of long bundles from the middle third of the humerus, a medial segment consisting of slightly shorter bundles from the epicondylic line and shaft of the humerus, and a lateral portion made up of still shorter bundles coming from the lateral epicondylic line. The demarcation between the three parts is not sharp, but the central part goes over largely into a tendon at its distal end, whereas the lateral and medial remain fleshy.

The ulnar attachment is to the coranoid process and the volar surface of the shaft below the coranoid for a distance of about 25 mm. Here it is associated with the ulnar head of the m. pronator teres.

MUSCLES OF THE FOREARM

In the forearm it seems best to group the muscles on the basis of position and innervation. With the exception of the m. brachioradialis, this also gives a satisfactory functional grouping. We may recognize an ulno-volar and a radio-dorsal group. These muscles pass from the arm and forearm to the forearm and hand. In the radio-dorsal group are found the mm. brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris, extensor digitorum longus, extensor digitorum brevis, supinator, extensor pollicis, and abductor pollicis longus. The ulno-volar group includes the mm. pronator teres, flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum sublimis, flexor digitorum profundus, and pronator quadratus. Because of their relation to the deep flexor of the digits, the lumbrical muscles might well be included here, but we have grouped them with the muscles of the hand.

The m. brachioradialis acts principally on the elbow, the pronators and supinators on the radio-ulnar joints, the other muscles on the radio-carpal joint or the joints of the hand.

We have designated as the m. extensor digitorum brevis what others have described as the mm. extensor indicis proprius and extensor digiti quinti proprius. In describing the muscles of the thumb we have recognized but one extensor, the equivalent of the long. Others have regarded the m. abductor longus as the equivalent of the long abductor and the short extensor.

THE ANTIBRACHIAL FASCIA

The fascia of the forearm of the orang-utan is heavy and would appear to form a limited exoskeleton. Perhaps it would be better to refer to this and similar structures and the intermuscular septa as a mesoskeleton.

It is thinnest over the proximal part of the volar surface where it covers the mm. brachioradialis and palmaris longus. It is thickest over the distal part of the volar surface and is well defined over the entire dorsal and medial surfaces. Just

proximal to the plane of the radio-carpal joint it is especially thick, forming the dorsal and volar carpal ligaments. The latter binds down and ensheaths the tendons of the mm. palmaris longus and flexor carpi radialis.

The fascia is associated especially with the brachioradial muscle and the ulnar carpal flexor. The medial part of the former toward its distal end goes over into the fascia as into an aponeurosis. Much the same condition exists laterally, but the relationship is not as marked. The condition over the distal part of the volar surface might be expressed by saying that the fascia forms an aponeurotic sheet between the mm. brachioradialis and flexor carpi ulnaris and is continuous with both of them.

M. brachioradialis

The brachioradial muscle is especially powerful, being one of the largest muscles of the upper extremity. It is fleshy in its proximal part, but fibrous in the distal. It covers rather more than the lateral half of the ventral surface of the forearm.

The humeral attachment is to the upper three-fifths of the lateral epicondylic line. The distal end is attached through a strong tendon to the volar surface of the radius in its lower fourth and into the antibrachial fascia. The lateral and central portions go over into the tendon, the medial ends in the fascia. The lateral portion also ends in part in the fascia. There is throughout continuity between the fascia and the tendon.

The radial carpal flexor has an origin from the deep surface of the brachioradial muscle.

M. extensor carpi radialis longus

This is a relatively small muscle made up of a fleshy belly in its proximal two-thirds and a long, slender tendon in the distal third. Its proximal attachment is to the lower 25 mm. of the lateral epicondylic line just distal to the attachment of the brachioradial muscle. It also has fibers from the

lateral intermuscular septum. The distal attachment is to the dorsolateral surface of the base of the second metacarpal.

In the first part of its course the m. extensor carpi radialis longus is covered ventrally by the brachioradial muscle and dorsally by the short radial carpal extensor, but its lateral surface is superficial. Then it is completely concealed by the two muscles just mentioned. About the distal fourth of the forearm its tendon becomes superficial. Just before it passes beneath the dorsal carpal ligament it is crossed and concealed by the long abductor of the thumb. Before reaching the base of the second metacarpal it is crossed on its dorsal surface by the tendon of the extensor of the pollex.

M. extensor carpi radialis brevis

The short radial carpal extensor is a much larger muscle than the long, being approximately twice as thick. The proximal half of the muscle is largely fleshy, although somewhat fibrous along its lateral and medial surfaces. The distal half is entirely tendinous.

The proximal attachment is to the lateral epicondyle of the humerus with the common extensor mass. The distal attachment is to the dorsal surface of the base of the third metacarpal.

In the distal part of the forearm it is crossed dorsally and laterally by the long abductor of the thumb. While under the dorsal carpal ligament it is crossed on its dorsal surface by the extensor of the thumb. Each of the radial carpal extensors lies in its own compartment as it passes under the dorsal carpal ligament.

M. extensor carpi ulnaris

The ulnar carpal extensor is the most medial of the dorsal muscles of the forearm. It is a relatively large muscle, fleshy in its proximal three-fifths, then fleshy and fibrous and finally tendinous in its distal fifth.

The proximal attachment is to the lateral epicondyle of the humerus through the common extensor mass and to the medial

margin and dorsal surface of the ulna in its upper three-fifths. The distal attachment is to the medial surface of the base of the fifth metacarpal.

This muscle is subcutaneous throughout its length. It lies in its own compartment under the dorsal carpal ligament just dorsal to the styloid process.

THE EXTENSORS OF THE SECOND TO THE FIFTH DIGITS

In the extensor mass of the orang-utan we have a more complete musculature than in man. There is a medial and a lateral tendon to each digit. The more lateral tendons are part of a mass which might be called the m. extensor digitorum communis for making comparisons with the musculature of man, but which for general purposes may better be referred to as the m. extensor digitorum longus. We prefer to use this latter term. The more medial tendons belong to what we have designated the m. extensor digitorum brevis. While this term does not seem entirely adequate, it is more descriptive of the conditions present than the terms m. extensor indicis proprius and m. extensor digiti quinti proprius, which are used by most workers. Others have described these two sets of muscles as having common distal attachments, but we have found the insertions quite independent of each other.

M. extensor digitorum longus

The long extensor of the digits occupies the middle of the dorsum of the forearm. In its upper part it lies between the short radial carpal extensor and the ulnar carpal extensor; toward the distal part between the long abductor of the thumb and the portion of the short extensor going to the fourth and fifth digits. Here it is superficial to the belly of the extensor of the pollex, but medial to its tendon.

The proximal attachment of the muscle is to the lateral epicondyle of the humerus through the common extensor mass, to the dorsal surface of the ulna near its lateral margin and to the fascia covering the dorsal surface of the long

abductor of the thumb. Through this fascia it may be said to have an attachment to the dorsal surface of the radius.

The segment to the second digit is blended at its proximal end with the m. extensor carpi radialis brevis and near its middle with the m. abductor pollicis longus. The segment to the fourth and fifth digits is blended proximally with the mm. extensor digitorum brevis and extensor carpi ulnaris. The segments to the several digits begin to separate from each other at a plane well above the middle of the forearm. The tendons pass through a compartment beneath the dorsal carpal ligament where they are superficial to the tendons of the short extensor.

The distal attachment is rather difficult to describe. The dorsal and lateral surfaces of the digits have an aponeurotic covering which is in continuity with, or an extension of, the tendons of this muscle and those of the interosseous and lumbrical muscles. In the region of the proximal phalanges the aponeuroses have anterior free borders which are in continuity with the free borders of the lumbrical muscles. More distally, the anterior margins are attached. Opposite the bases of the proximal phalanges transverse fibers forming a band about 20 mm. wide connect each tendon with the adjacent ones. Mediad this band, which may be termed the dorsal interphalangeal ligament, is attached to the tendon of the abductor of the fifth digit, laterad to that of the first dorsal interosseous muscle. The tendons of the short extensors end in part in this ligament.

The tendons of the long extensor are but loosely attached to the proximal phalanges and largely through areolar tissue. The central part of each tendon attaches to the base of the intermediate phalanx, the lateral parts pass over it. The tendon is loosely attached to the shaft of the intermediate phalanx and ends on the base of the terminal phalanx. It is readily separable from the capsule of the metacarpophalangeal joint, but ends in part in the capsules of the interphalangeal joints.

M. extensor digitorum brevis

The short extensor of the digits may be conveniently divided into two segments, one sending tendons to the second and third digits, the other to the fourth and fifth.

The lateral segment, which is often described as the m. extensor indicis proprius, lies deep to the long extensor of the digits and the extensor of the thumb in the distal part of the forearm. The proximal attachment is to the interosseous membrane and the adjacent margins of the radius and ulna in the upper part of the distal third of the forearm. It passes through a compartment under the dorsal carpal ligament in common with the tendons of the long extensor, but deep to them. On the dorsum of the hand the tendons of the short extensor lie medial to those of the long. The tendons end largely in the capsules of the metacarpophalangeal joints and through these on the proximal phalanges.

The medial segment which sends tendons to the fourth and fifth digits arises in part from the common extensor mass and in part from the septa between it and the lateral segment and the m. extensor carpi ulnaris. At the wrist it passes through a separate compartment deep to the dorsal carpal ligament. At this level it divides into two tendons, one for the fourth digit and one for the fifth. These end in the capsules of the metacarpophalangeal joints and on the proximal phalanges. This segment is often referred to as the m. extensor digiti quinti proprius.

M. supinator

The supinator lies deep in the upper part of the forearm. It is well developed and largely fleshy. It is attached proximally to the lateral epicondyle of the humerus and to the dorsolateral surface of the ulna in the upper third. The fibers pass obliquely laterad and distad to end on the radius. The muscle practically surrounds the proximal fourth of this bone, being attached to its dorsal, lateral, and volar surfaces. The more distal portion of the muscle is attached only to the dorsal surface of the radius just behind the insertion

of the m. pronator teres. These fibers approach the horizontal, while the proximal fibers are more oblique. Some of the former bundles overlap the ulnar origin of the long abductor of the thumb.

M. extensor pollicis

The extensor of the thumb is one of the deep muscles of the distal two-thirds of the forearm. The proximal attachment is to the interosseous membrane and the adjacent surfaces of the ulna and radius, in this latter instance largely through the fascia of the long abductor of the thumb. This upper attachment, in general, is just proximal to that of the short extensor of the digits. It passes onto the dorsum of the thumb getting its first attachment to the capsule of the metacarpophalangeal joint and through that to the first phalanx. It then continues to the capsule of the interphalangeal joint and the base of the terminal phalanx. At the capsule of the metacarpophalangeal joint its insertion is in part continuous on the ulnar side with that of the transverse head of the adductor muscle, on the radial side with part of the short abductor.

The muscle passes through its own compartment under the dorsal carpal ligament crossing superficial to the radial carpal extensors.

M. abductor pollicis longus

The long abductor of the thumb is a superficial muscle in the distal half of the dorsal surface of the forearm. At the wrist it passes to the lateral surface and at its distal attachment it is on the ventral surface of the hand.

The proximal attachment is to the dorsal surface of the radius in its distal half falling short of the radiocarpal joint by about 30 mm. Cephalad it reaches the supinator. Here some of the more medial fibers have an attachment to the interosseous membrane and ulna. A little below its middle the muscle separates into two parts and the more ventral segment, in turn, has two tendons. The tendon of the dorsal

segment and the smaller tendon of the ventral segment are attached to the proximal end of the first metacarpal. The larger tendon of the ventral portion attaches to the volar surface of the greater multangular bone.

This muscle has been described as representing both the long abductor and the short extensor.

M. pronator teres

The m. pronator teres lies on the volar surface of the proximal part of the forearm and forms the medial boundary of the cubital fossa. It is almost entirely covered on its ventral surface by the mm. palmaris longus and brachioradialis. The pronator, in turn, covers the distal end of the brachial muscle. The proximal attachment is by two heads, one from the medial epicondyle of the humerus and one from the volar surface of the ulna. The median nerve passes between the two heads. The upper half of the muscle is very closely united to the other muscles of the volar group. Distally, it is attached to the lateral margin of the radius in its second fourth. The muscle is heavy and largely fleshy, but it becomes fibrous on its volar surface in its distal half.

M. pronator quadratus

This is a flat quadrilateral muscle deeply placed in the distal fourth of the forearm. It is attached medially to the volar surface of the ulna, the more distal fibers extending somewhat onto the medial surface. Its lateral attachment is to the volar surface of the radius. It is largely fleshy.

M. flexor carpi radialis

The radial carpal flexor is another powerful muscle of the orang-utan. Proximally, it lies dorsal to the m. palmaris longus, distally lateral to the latter. In the middle of the forearm it is covered laterally and ventrally by the brachioradial muscle, and in the distal part by the antibrachial fascia into which the brachioradial muscle is continued.

It has several proximal attachments, one to the humerus with the common flexor mass, another to the ulna with the m. pronator teres. It is also attached to the volar surface of the radius medial to the distal attachment of the round pronator and by a fibrous arch extending from the distal end of the latter to the radial attachment of the brachioradial muscle. This arch bridges the deep flexor of the digits. It attaches to the deep surface of the brachioradial muscle for a distance of about 30 mm. a little above the radiocarpal joint. The distal attachment is to the volar surface of the base of the second metacarpal.

It passes through its own compartment in the volar carpal ligament and, like the m. palmaris longus, is covered by the antibrachial fascia connecting the mm. brachioradialis and flexor carpi ulnaris. The tendon forms most of the distal third of the muscle, but fleshy bundles are found as far is the wrist.

M. flexor carpi ulnaris

The ulnar carpal flexor is a broad flat muscle covering the medial part of the volar surface of the forearm. Its proximal attachment is to the medial margin of the olecranon and then through the antibrachial fascia to the dorsal and medial margins of the ulna nearly to the distal end of the bone. The distal attachment is fleshy and fibrous to the pisiform bone. The tendon of the muscle forms its ventral margin.

It was noted under the brachioradial muscle that the antibrachial fascia connects it with the ulnar carpal flexor. The fascia practically ensheaths the latter muscle, and in its distal two-thirds forms the connection between the muscle and the ulna. On its deep surface the muscle unites with the slip of the superficial digital flexor for the fifth digit. The attachment to the olecranon blends a little with the deep flexor of the digits. The ulnar nerve runs along its deep surface.

M. palmaris longus

In the specimen at hand the long palmar muscle consists of a fleshy belly in its proximal half and a flattened tendon in its distal. It is superficial throughout its length. The proximal attachment is to the medial epicondyle of the humerus with the common flexor mass, to the antibrachial fascia, and to the septa between it and the adjacent muscles. The distal attachment is to the palmar aponeurosis.

In its upper part it is covered by a relatively thin layer of fascia; in its lower by the strong fascial layer connecting the brachioradial muscle with the ulnar carpal flexor. At the wrist it passes through its own compartment in the volar carpal ligament.

M. flexor digitorum sublimis

The superficial flexor of the digits forms an intermediate muscle mass completely concealed in the proximal part of the forearm by the mm. brachioradialis, pronator teres, flexor carpi radialis, palmaris longus, flexor carpi ulnaris, and the antibrachial fascia connecting them with each other. It has a general proximal attachment to the medial epicondyle of the humerus through the common flexor mass, to the proximal part of the ulna through a blending with the ulnar carpal flexor, and to the proximal half of the radius. The distal attachments are to the intermediate phalanges of the second, third, fourth, and fifth digits. The tendons are perforated by those of the deep flexor about the level of the metacarpophalangeal joints.

The proximal attachments are rather complex, and it will be most convenient to analyze the segment for each digit separately. The segment for the second digit begins proximally on the medial epicondyle of the humerus and the upper part of the ulna. It has a short, thick, piriform belly, largely independent of the common flexor mass. It fact, one could think of it as a separate muscle interposed between the dorsal and ventral segments of the common mass. After

a course of about 30 mm., most of the muscle goes over into a small terminal tendon, but there is a flat, fleshy band which joins with the tendon to the third digit. The intermediate part of the muscle is a peculiar combination of fibrous and fleshy tissue. In its upper part it is fibrous on the ulnar surface and fleshy on the radial. In its lower part the tissues are reversed. A little above the middle of the forearm it is placed between the segments to the fourth and fifth digits. It then passes dorsal to the tendons for the third and fourth digits to end on the intermediate phalanx of the second digit. Opposite the base of the first phalanx there is a long mesotendon.

The segment to the third digit has its proximal attachment to the humerus through the common mass, being quite closely blended with the segments for the fourth and fifth digits. It has, in addition, an attachment to the volar surface of the radius in its second fourth. This attachment extends obliquely across the surface of the bone from medial to lateral more or less closely united with the mm. flexor carpi radialis and flexor digitorum profundus. This is about in the plane of the distal attachment of the m. pronator teres. It receives a small slip from the segment to the second digit. Its tendon is perforated by that of the deep flexor and also has a long mesotendon. In the first part of its course this segment is placed between those for the fourth and second digits. In the distal part of the forearm it is placed between the segment for the second digit and the radial carpal flexor. At the wrist it is superficial to the former.

The segments to the fourth and fifth digits lie superficial to those just described. The portion for the fourth digit has its proximal attachment to the medial epicondyle of the humerus with the ulnar carpal flexor, and to the proximal part of the ulna with the mm. palmaris longus, flexor carpi radialis, pronator teres, and the segment to the second digit. A few of its fibers are blended with fibers coming from the radius. It is fibrous in the proximal fourth of the forearm. As it passes to its distal attachment it crosses the segments

for the second and third digits from lateral to medial. Its tendon is also perforated and has a long mesotendon.

The segment to the fifth digit has its attachment through the dorsal part of the common flexor mass to the humerus and ulna, being united with the ulnar carpal flexor. In its course it is crossed by none of the other tendons, but simply runs along the volar surface of the corresponding segment of the deep flexor. Its distal attachment is to the intermediate phalanx. It is perforated by the deep flexor and has the long mesotendon described for the others.

M. flexor digitorum profundus

The deep flexor of the digits is a large muscle mass deeply placed on the volar surface of the forearm. It is overlaid by the other volar muscles with the exception of the m. pronator quadratus. The proximal attachment is to the volar surface of the radius and ulna in the upper two-thirds of the forearm. The distal attachment is to the terminal phalanges of the second, third, fourth, and fifth digits. The segment from the radius is fairly distinct from the rest of the mass and goes over into a tendon which is attached to the distal phalanx of the second digit. Each tendon has a mesotendon that joins that of the superficial flexor. The radial attachment extends from the mm. supinator and pronator teres proximally to the m. pronator quadratus distally. It is largely fleshy in its dorsal part, but fibrous in the volar as high as the middle of the forearm.

The ulnar head is attached to the interosseous membrane and to the volar surface and medial margin of the shaft of the ulna in its proximal two-thirds. It extends along the medial margin of the olecranon to within a centimeter of its tip.

The slip to the third digit is fleshy on its dorsal surface nearly to the wrist, but tendinous on the ventral from about the middle of the forearm. On the slip to the fourth digit the fleshy bundles do not extend as far distally and the tendon extends farther proximally. For this slip the tendon is

double from the middle of the forearm to a point distal to the attachment of its lumbrical. The segment to the fifth digit is fleshy in the proximal half of the forearm and tendinous throughout the rest of its course.

THE MUSCLES OF THE HAND

Here we have used the conventional grouping, dividing the muscles into those of the thumb, those of the fifth digit, the lumbrical and interosseous.

The muscles of the thumb (figs. 8, 9, 10, 11)

Here are found a short abductor, a short flexor, an opponens, and an adductor. The abductor, which is the most superficial muscle of the group, passes from the transverse carpal ligament and greater multangular bone to the base of the first phalanx. The opponens, which is deep to the abductor, consists of two quite distinct parts. One, a small rounded slip, extends from the greater multangular bone to the distal end of the metacarpal; the other, the main portion of the muscle, extends from the greater multangular bone and transverse carpal ligament to the shaft of the metacarpal throughout its length. The flexor lies volar and medial to the opponens. It is divisible into three portions which have proximal attachments to the transverse carpal ligament, the greater multangular bone, and the first metacarpal. The distal attachment is to the base of the proximal phalanx. The adductor is for the most part medial to the flexor. It also consists of three parts with proximal attachments to the second and third metacarpals and the capitate bone, and distal attachments to the base of the first phalanx and to the metacarpal.

The muscles of the fifth digit (figs. 8, 9)

In this group are a flexor, an abductor, and an opponens. For convenience we have included the m. palmaris brevis. The abductor and flexor are superficial. The abductor

passes from the pisiform and hamate bones to the base of the first phalanx. The flexor extends from the transverse carpal ligament to the base of the first phalanx. The opponens lies deep to the two muscles just described and passes from the transverse carpal ligament and hamate bone to the shaft of the metacarpal.

THE LUMBRICAL MUSCLES

These are four small round muscles which pass from the tendons of the deep flexor to the membranous expansions of the tendons of the long extensor of the digits.

THE INTEROSSEOUS MUSCLES

There are seven well-developed interosseous muscles, three of which are volar and four dorsal. They have proximal attachments chiefly to the shafts of the metacarpal bones, the volar muscles by a single head, the dorsal in each case by two heads. Distally, they attach to the bases of the proximal phalanges of the second to the fifth digits and go over into the membranous expansions on the dorsum of the phalanges.

M. abductor pollicis brevis

This is a small triangular muscle taking origin from the transverse carpal ligament and from the ridge on the greater multangular bone and converging into the lateral side of the first phalanx of the pollex.

M. opponens pollicis

Just under cover of the short abductor is a small, rounded slip which passes from the ridge of the greater multangular bone to the lateral side of the distal end of the metacarpal.

At a deeper level lies the larger segment. This is a well-developed quadrangular mass. It has an extensive origin from the ridge of the greater multangular bone and the transverse carpal ligament. The distal attachment is to the lateral side of the shaft of the metacarpal throughout its length.

The muscle lies deep to the short abductor and lateral to the flexor.

M. flexor pollicis brevis

This is a short thick muscle lying volar and medial to the opponens and deep to the abductor. It has a superficial, an intermediate, and a deep segment. The superficial portion arises from the transverse carpal ligament; the intermediate from the greater multangular bone. The deep segment is subdivided. One part arises from the lateral aspect of the volar surface of the metacarpal, the other from the medial aspect and the greater multangular. The entire muscle inserts into the lateral side of the base of the first phalanx partly medial to, and partly under cover of, the insertion of the abductor.

M. adductor pollicis

This is a triangular muscle made up of three distinct portions—oblique and transverse, as in man, and a third more dorsal part.

The transverse head arises in its proximal part from the third metacarpal and in its distal from the second. It has a narrow insertion into the medial side of the base of the first phalanx.

The oblique head which is narrower than the transverse comes from the bases of the second and third metacarpals and from the capitate bone. Its medial half overlies the lateral portion of the transverse segment. Laterally it extends to fill the space between the first and second metacarpals and is under cover of the deep head of the flexor. Its fibers insert in common with those of the transverse head.

The third and most dorsal segment arises immediately adjacent to the transverse head from the second metacarpal and the fascia between the second and third. There is a narrow insertion into the medial side of the distal end of the shaft of the first metacarpal.

M. abductor digiti quinti

This is a cylindrical muscle forming the medial part of the hypothenar eminence. It passes from the pisiform and hamate bones to the medial side of the base of the first phalanx of the fifth digit.

M. flexor digiti quinti brevis

The short flexor lies just radiad to the abductor. It arises from the ulnar end of the transverse carpal ligament. At its insertion on the proximal phalanx it is quite closely united with the abductor which it partially envelops.

M. opponens digiti quinti

The musculus opponens is a fan-shaped muscle arising from the hamate bone and from the transverse carpal ligament deep to the attachment of the short flexor. It spreads out to insert on the shaft of the fifth metacarpal in its whole length. It is overlaid by both the abductor and short flexor.

Mm. lumbricales

The lumbrical muscles are well represented. The origins are slightly different from those in man. The most lateral arises by a single head from the lateral side of the deep flexor tendon to the index-finger. The second muscle arises by two heads from the adjacent sides of the tendons to the index- and third fingers. These heads unite about halfway between the proximal and distal attachments. The third arises mainly from the lateral side of the deep flexor tendon to the fourth digit, but a very delicate slip, seen only on the right side, comes from the medial side of the tendon to the third digit and joins the former. The most medial lumbrical has a single head of origin from the lateral side of the tendon to the fifth digit. The proximal attachments are all about opposite the carpometacarpal joints. The distal attachment in each case is to the tendon of the long extensor.

Mm. interossei

The first volar interosseous muscle has its proximal attachment to the ulnar surface of the shaft of the second metacarpal. It is covered on its volar surface by the transverse head of the adductor of the thumb, and some of the fibers arise from the fascia between the two muscles.

The second volar interosseous muscle comes from the radial surface of the shaft of the fourth metacarpal and from a sheet of fascia which overlies the interosseous muscles of the third and fourth interspaces.

The third volar interosseous muscle comes from the radial surface of the shaft of the fifth metacarpal and from the fascia covering it.

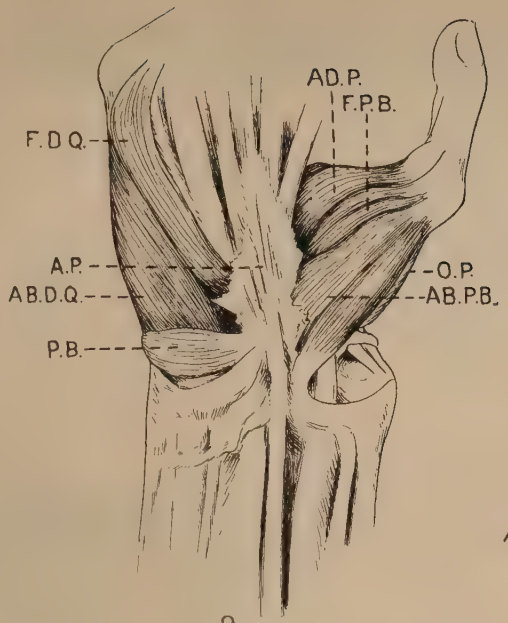
The first dorsal interosseous muscle arises by one head from the radial surface of the shaft of the second metacarpal and by a second head from the ulnar surface of the base of the first metacarpal and the adjacent portion of the shaft. It lies dorsal to the adductor of the thumb.

The second dorsal interosseous muscle comes from the radial surface of the shaft of the third metacarpal and from the dorsal margin of the shaft of the second. It is just dorsal to the attachment of the first volar interosseous muscle.

The third dorsal interosseous muscle comes from the ulnar surface of the shaft of the third metacarpal and from the dorsal margin of the shaft of the fourth just dorsal to the attachment of the second volar interosseous. It also attaches to the fascia over its volar surface.

The fourth dorsal interosseous muscle comes from the ulnar surface of the shaft of the fourth metacarpal and the dorsal margin of the shaft of the fifth.

The distal attachments are all similar. Each muscle becomes tendinous toward its distal end. The tendon joins that of the short extensor of the digits as the latter gains attachment to the capsule of the metacarpophalangeal joint. It then continues distally to unite with the tendon of the long extensor over the dorsum of the proximal phalanx. Oppo-



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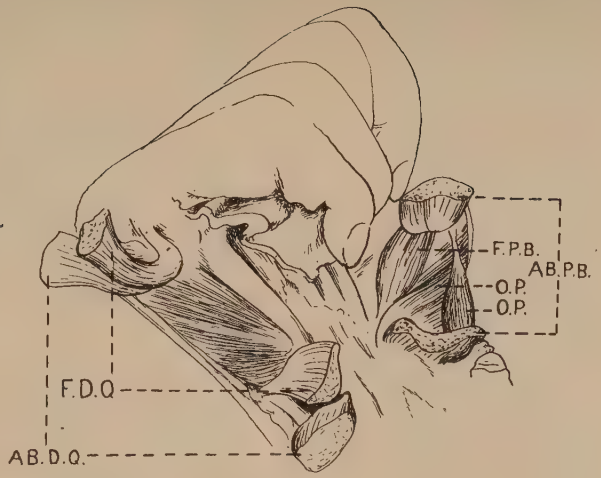

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Fig. 8 The superficial musculature of the palm. *Ab.D.Q.*, m. abductor digiti quinti; *Ab.P.B.*, m. abductor pollicis brevis; *Ad.P.*, m. adductor pollicis; *A.P.*, aponeurosis palmaris; *F.D.Q.*, m. flexor digiti quinti; *F.P.B.*, m. flexor pollicis brevis; *O.P.*, m. opponens pollicis; *P.B.*, m. palmaris brevis.

Fig. 9 The second layer of thenar and hypothenar muscles. *Ab.D.Q.*, m. abductor digiti quinti; *Ab.P.B.*, m. abductor pollicis brevis; *F.D.Q.*, m. flexor digiti quinti; *F.P.B.*, m. flexor pollicis brevis; *O.D.Q.*, m. opponens digiti quinti; *O.P.*, m. opponens pollicis.

site the base of the phalanx the tendon is quite firmly bound to the bone. The distal attachments of the several muscles are located as follows: the first volar interosseous on the ulnar side of the second digit; the second on the radial side of the fourth digit; the third on the radial side of the fifth digit; the first dorsal interosseous on the radial side of the second digit; the second on the radial side of the third digit; the third on the ulnar side of the third digit, and the fourth on the ulnar side of the fourth digit.

THE ACTION OF THE MUSCLES

In discussing the action of the muscles of the orang-utan we have considered them entirely on the basis of attachments and relations to the axes of the joints they cross. This makes it necessary for us to assume that a muscle can act not only as a whole, but also in parts. This assumption is open to the same criticism here that it is in dealing with any animal. We have not adequate personal information to add anything to the discussion of the question.

The superficial muscles of the shoulder-girdle act both on the girdle and on the head and neck. The m. trapezius acting as a whole effects lateral rotation and retraction of the girdle. The upper segments assist in its elevation; the lower in depression. If the shoulder-girdle is fixed, the muscle will bring about extension of the head and rotation of the face to the opposite side. The sternocleidomastoid muscle acts primarily on the head, neck, and thorax. At the atlanto-occipital joint the greater part of the muscle must be an extensor as it passes dorsal to the transverse axis. At the atlanto-epistropheal articulation it will rotate the face to the opposite side. At the lower cervical joints the muscle is a flexor. It bends the head and neck to the same side. Walmsley, in the eleventh edition of Quain's Anatomy, discusses at some length the m. sternocleidomastoideus as a flexor of the head and vertebral column. It is quite clear, however, that he does not distinguish between its action at the atlanto-occipital and intervertebral joints. With the

head fixed, the muscle will elevate the sternum and ribs at the costovertebral joints.

The deep muscles of the shoulder-girdle, with the exception of the subclavian and omocervical, may act both on the sternoclavicular and acromioclavicular joints. The two specified are limited to the former articulation. The omo-occipital produces elevation, medial rotation, and a small

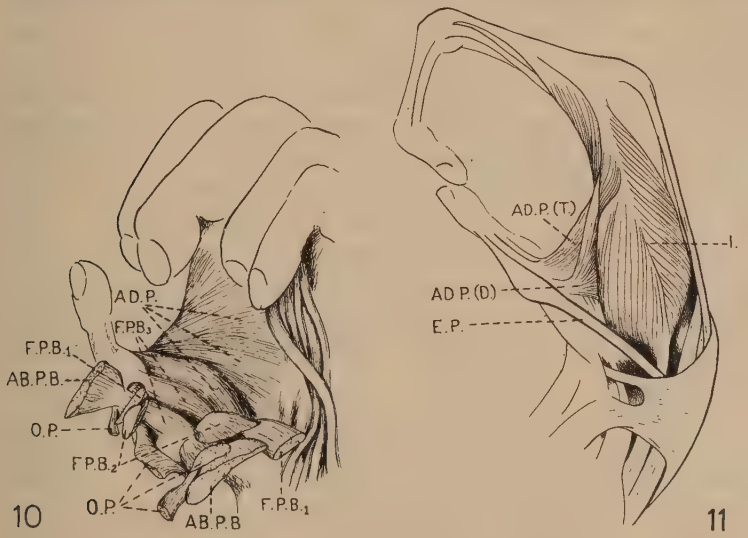

Fig 10 The deep muscles of the thumb. *Ab.P.B.*, m. abductor pollicis brevis; *Ad.P.*, m. adductor pollicis; *F.P.B.*, m. flexor pollicis brevis, superficial portion; *F.P.B.*$_2$, m. flexor pollicis brevis, intermediate portion; *F.P.B.*$_3$, m. flexor pollicis brevis, deep portion; *O.P.*, m. opponens pollicis.

Fig. 11 Lateral view of the hand. *Ad.P.*(*D*), m. adductor pollicis, dorsal portion; *Ad.P.*(*T*), m. adductor pollicis, transverse head; *E.P.*, tendon of the m. extensor pollicis; *I.*, m. interosseus dorsalis primus.

amount of retraction; the rhomboid, retraction, elevation, and medial rotation. The omocervical muscle will take part principally in elevation, but may assist in retraction. The m. levator scapulae is practically limited to elevation. The m. serratus anterior may best be considered in two parts—the upper a protractor, the lower a lateral rotator. The

lesser pectoral muscle rotates mediad, protracts, and depresses. The m. subclavius is a depressor.

The long muscles of the shoulder, while having their first action on the shoulder-joint, may also act on the girdle. The greater pectoral muscle adducts, rotates mediad, and flexes at the shoulder-joint. It is a protractor of the girdle. The m. latissimus dorsi adducts, rotates mediad, and extends at the shoulder-joint. It depresses the girdle. The m. latissimo-condyloideus increases the power of the m. latissimus dorsi in adduction and extension.

The short muscles of the shoulder act only on the shoulder-joint. The deltoid muscle is first of all an abductor, but through its well-developed dorsal portion is also a strong extensor and lateral rotator. Parts of it may be considered as assisting in adduction, flexion, and medial rotation. The supraspinous muscle is an abductor; the infraspinous and lesser teres are lateral rotators. The m. teres major extends, adducts, and rotates mediad. The subscapular muscle is a medial rotator. The coracobrachial muscle is an adductor and flexor.

The muscles of the arm act principally on the radio-ulnar and elbow-joints, but the m. biceps and the long head of the m. triceps may act on the shoulder-joint. The m. triceps brachii is an extensor at the elbow and, through its long head, an accessory extensor at the shoulder. The m. anconeus is an extensor of the elbow-joint and aids in the lateral movement of the ulna during pronation. The m. biceps is first of all a strong supinator. The absence of the lacertus fibrosus indicates that its action in flexion at the elbow has been reduced. As an accessory muscle of the shoulder-joint it may assist in abduction, adduction, and flexion. The brachial muscle is a powerful flexor of the elbow-joint.

From the standpoint of function, the radiodorsal muscles are a mixed group. The brachioradial muscle is a flexor of the elbow-joint and, as in man, may assist in either pronation or supination if one starts from the proper primary

position. The two radial carpal extensors are both extensors at the wrist-joints. The long muscle is a strong radial abductor, the short one somewhat weaker. The long muscle is well ventral to the transverse axis at the elbow, the short one is also volar, but much nearer the axis. The ulnar carpal extensor is an extensor of the radiocarpal and intercarpal joints and an ulnar abductor. The long extensor of the digits is an extensor of the metacarpophalangeal joints and an accessory extensor of the interphalangeal and wrist-joints; the short extensor will act only on the metacarpophalangeal and wrist articulations. The supinator is practically limited to supination. The extensor of the thumb will extend it and abduct the hand radiad. The long abductor of the thumb will abduct at the carpometacarpal joint and abduct the hand radiad.

The ulnovolar group is made up of pronators and flexors. The two pronators act on the radio-ulnar joints. The humeral head of the m. pronator teres flexes at the elbow. The radial carpal flexor flexes the wrist-joints. It is also an accessory pronator and a weak radial abductor. The ulnar carpal flexor flexes the wrist-joints and abducts the hand ulnarward. The superficial digital flexor flexes the proximal interphalangeal, the metacarpophalangeal, and wrist-joints. The deep flexor flexes the terminal interphalangeal articulations as well as those mentioned for the superficial.

For the short muscles of the thumb the principal action in each case, except for the m. opponens pollicis, is indicated by the name of the muscle. The opponens rotates mediad. The abductor, flexor, and adductor are continued into the dorsal aponeurosis and thus become extensors of the interphalangeal joint. The abductor is also a flexor. It may be mentioned that the adductor is especially strong.

Again, with the short muscles of the fifth digit, the names are an adequate expression of the principal function. Here, too, the flexor and abductor extend into the dorsal aponeurosis.

The lumbricals flex and move the digits radiad at the metacarpophalangeal joints and extend them at the interphalangeal.

The interosseous muscles are so placed that the volar adduct to the plane of the third digit; the dorsal abduct. Both groups flex at the metacarpophalangeal joints and extend at the interphalangeal.

In the paragraphs that follow some of the more interesting details relating to the several muscles are listed. While the items are not at all equally important, we feel that a résumé of this type is worth while. The occasional use of quotation marks is to indicate that the information given is from the work of others.

The m. trapezius is heavy and has no aponeurotic area.

The ligamentum nuchae is vestigial at best and probably should not be given the name.

The general instability of the cranial end of the m. sternocleidomastoideus is expressed by accessory slips to the skull and cephalic musculature. The sternal and clavicular portions unite about the middle of the neck "which is not the usual condition for the orang-utan."

The m. omo-occipitalis is entirely independent of the rhomboid mass. "Ordinarily the separation is not so complete."

The m. rhomboideus extends cephalad as far as the epistropheus. A separation into major and minor portions is not indicated.

The m. omocervicalis extends from the atlas to the clavicle "which is the usual condition for the anthropoids."

The m. levator scapulae is made up of four segments independent of each other almost to their scapular attachment.

The m. serratus anterior is readily separable into two parts quite different in their main function. Sonntag notes that their nerves remain separate.

At its distal end the m. pectoralis minor goes over in part into the coracoclavicular ligament. "It is often continued into one of the coracoid ligaments."

The m. subclavius has its proximal attachment to the costal cartilage.

There is a heavy costocoracoid membrane.

The m. pectoralis major has no clavicular portion, but consists of manubrial, sternochondral, and costo-abdominal segments.

The m. latissimus dorsi is attached throughout the entire length of the iliac crest, but has no costal or scapular attachments. In one case Sonntag has described a costal origin. Near its humeral end it gives origin to the m. latissimo-condyloideus and sends a slip to join the tendon of the m. teres major.

The m. latissimo-condyloideus reaches as far as the medial epicondyle.

The m. deltoideus is attached to the infraspinous fascia nearly to the vertebral margin.

The m. coracobrachialis is readily separable into two segments.

The m. triceps has an especially large, long head.

The m. anconeus is inseparable from the triceps.

The two heads of the m. biceps are separable nearly to the elbow. There is no lacertus fibrosus.

In the m. brachialis one may recognize three parts.

The m. brachioradialis is especially heavy. From its deep surface it sends a bundle to the m. flexor carpi radialis. It is intimately related to the antibrachial fascia.

The antibrachial fascia on the distal part of the volar surface is essentially aponeurotic and forms one of the most interesting features of the forearm.

Each digit except the first has two extensors, a long and a short. The tendons of the long extensors go over into the dorsal digital aponeurosis much the same as the common extensor in man. Opposite the bases of the proximal phalanges they are connected by heavy bands of transverse fibers which, for want of a better term, we have called the dorsal interphalangeal ligaments. The tendons of the short extensors end in part in these ligaments and in part in the

capsules of the metacarpophalangeal joints and on the proximal phalanges.

The m. extensor pollicis is the equivalent of the long extensor.

The m. abductor pollicis longus has two bellies and three tendons of insertion, one of which goes to the greater multangular bone. Though the muscle does not go beyond the metacarpal bone one portion is often described as the short extensor.

The m. flexor carpi radialis has proximal attachments to the humerus, ulna, radius, and the tendon of the m. brachioradialis.

The m. flexor carpi ulnaris is closely associated with the antibrachial fascia.

The m. flexor digitorum profundus has a segment from the radius to the second digit which is almost completely independent of the rest of the muscle. Bryce has noted that this separation is a distinctly human character.

The m. flexor pollicis longus is completely wanting.

The m. opponens pollicis has a small accessory portion.

The m. flexor pollicis brevis may be separated into three segments.

The m. adductor pollicis has an oblique and two transverse segments, one of the latter passing from the second metacarpal to the first.

SUMMARY

In analyzing the muscles of the orang-utan we have kept in mind that they are used for locomotion as well as for seizing and holding objects. As one observes the method of locomotion, he appreciates the necessity of a well-developed musculature for movements of the shoulder-girdle; for movements of the shoulder-joint, especially extension and rotation; for movements of the elbow-joint, especially for flexion, for pronation and supination, and for flexion of the digits. We find these groups exaggerated, with the exception of the last, where the length of the digits gives

great mechanical advantage. In our studies, we have had an opportunity to observe two living animals, and with these in mind we have tried to interpret the musculature in terms of the orang-utan rather than in terms of man.

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THE LITERATURE ON THE GROWTH AND PHYSICAL DEVELOPMENT OF THE FETUS, INFANT, AND CHILD: A QUANTITATIVE SUMMARY

RICHARD E. SCAMMON

Department of Anatomy and Institute of Child Welfare, University of Minnesota

EIGHT FIGURES

One of the most serious difficulties in the study of physical development of the fetus, infant, and child lies in assembling the literature on the various phases of this subject. The diversities of interests of the various workers in the field have led them to present their results in the most unrelated types of publication, and since no review journal deals with all phases of the subject, many worthy papers and even books pass unnoticed for years.

The writer has recently had occasion to go over a bibliography of some 5400 titles on this subject, and the results seem to be of sufficient interest to warrant publication of a quantitative summary of the findings. The material covered includes all the phases of the anatomy and growth of the human body from birth to maturity, as well as a considerable amount of literature on the growth and structure of the fetus, as distinct from that of the embryo. Titles appearing since 1925 are not included. It is not to be supposed that this bibliography is a complete one. In point of fact, it is probable that the number of separate papers, pamphlets, and books, of a scientific nature, dealing with subjects in this field is much larger, and that it probably lies somewhere in the neighborhood of 7500 titles. While, on the whole, the omissions from this total in the present list are probably fairly equally distributed, it is likely that the Scandinavian and Italian

publications are less completely represented than those in English, French, and German, and that the relative number of missed titles in the last decade (1915-1925) is greater than in the preceding ones.[1] It is thought, however, that with these exceptions the bibliography analyzed is of sufficient size to give an approximately correct idea of the general distribution of this material as regards time, subject, language, and vehicle of publication.

THE DISTRIBUTION OF TITLES WITH RESPECT TO TIME

Table 1 and figure 1 show the distribution of the titles in this bibliography with respect to time of publication and illustrate graphically the development of interest in this subject. There have been found eleven titles dating in the sixteenth century which can properly be classified as falling in this field. The first publication seems to be that of Gabrielo de Zerbi or Zerbis, which appeared in 1502.[2] There are thirty titles in the seventeenth century. In the eighteenth century, with the increase in anatomical laboratories, better organization of hospitals, improvement in methods of publication, and particularly with the widespread requirement of the publication of a thesis rather than a mere program of a disputation for the doctorate in medicine, the number of publications

[1] Because of the length of time which frequently elapses before references to publications in obscure or unusual sources appear in the more available literature.

[2] Possibly first published as a part of his "Anatomia corporis humani". There is no reference to de Zerbis in Hahn (Repertorium bibliographicum in quo libri omnes ab arte typographica inventa usque ad annum MD . . . . etc., 1831) nor in other lists of incunabula which I have examined. The part of de Zerbis' work dealing with developmental anatomy was also published (in part, at least) by Johann Dryander or Eichmann, some thirty-five years later (Anatomiae, hoc est, corporis humani dissectionis pars prior, in qua singula quae ad caput spectant recensentur membra . . . . dilineatur. Item: Anatomia porci ex traditione Cophonis: infantis, *ex Gabriele de Zerbis*. 4°, Marpurgi, E. Cervienormis, 1537). Most citations of de Zerbis' work are to this publication. So far as I can discover, this study did not appear under a descriptive title until the Dryander publication; at least, I cannot find it so listed in any available bibliography nor in the catalogs of the Surgeon-General's Library, the British Museum, or the Bibliotheque Nationale. De Zerbis died in 1505. There is a short note on his life in Haller (Bibliotheca anatomica, T. 1, p. 153, Tiguri, 1774) and a much longer account in Tiraboschi (Storia della letteratura italiana, T. 7, Roma, 1782-1797).

showed a marked increase, there being 199 for this period in the bibliography.

The number of publications shows a marked rate of increase throughout the nineteenth century, more than doubling in each of the three first quarters, and rising to 1759 for the period between 1875 and 1900. The number of separate titles on the subject in the first quarter of the twentieth century shows a continued increase, for the bibliography contains 2745 titles for the years 1901 to 1925, inclusive. It is very likely that the total number in this last interval is really much greater than this figure indicates, since many of the titles in the bibliography have been gathered from secondary sources and it may be a decade or more after a paper has appeared before it is located by this method. Therefore, it is probably not an overestimate to place the total number of papers on this phase of human biology appearing since 1900 in the neighborhood of 3500.

The general course of growth in this literature is more easily followed if the figures are placed in a percentage form as shown in figure 1. In the first 200 years of the period under consideration (1500 to 1700) only 0.75 per cent of all the publications in this bibliography made their appearance, or approximately two-tenths of 1 per cent per quarter-century. Between 1700 and 1800, approximately 3.6 per cent of all the listed titles were published—a mean of 0.93 per cent per quarter-century. In the first quarter of the nineteenth century 1.38 per cent of all the listed publications on the subject came into print, or one-third as many as in the 300 years preceding this period. The percentage for the second quarter of the nineteenth century is 2.70, and for the third quarter it is 7.36. In the last quarter (1875 to 1900) the number rose to 32.8 per cent, or almost one-third of all listed publications. The percentage of publications appearing since 1900 is 51.27, or slightly over one-half of all listed articles, and, as indicated in the previous paragraph, the actual proportion in this period is probably even higher. It appears from these figures that even the interruption of the war years hardly reduced the activity in this form of research.

TABLE 1

Distribution of titles on growth and physical development according to dates of publication

DATES	TOTAL NUMBER OF TITLES	PER CENT OF TOTAL	MEAN PER CENT PER DECENNIUM
1500–1600	11	0.21	0.021
1600–1700	30	0.56	0.056
1700–1800	199	3.71	0.371
1800–1825	74	1.38	0.552
1825–1950	145	2.70	1.082
1850–1875	395	7.37	2.947
1875–1900	1759	32.80	13.122
1900–1925	2749	51.27	20.507
Sum	5362	100.00	

DISTRIBUTION OF TITLES WITH RESPECT TO SUBJECT

Any classification of this kind of material according to subject must be a somewhat arbitrary one, for any division of the field is more or less conventional, and the assignment of material to the various subdivisions is often a matter of personal interpretation. However, admitting these limitations, such a classification has a certain value in estimating the activity in the broader divisions of the subject. In the following classification nine main subheads have been recognized:

1. General growth, under which heading is included growth in height and weight, growth of the external dimensions of the body, and changes in body form and proportions.
2. The skeleton and musculature.
3. The digestive and respiratory systems.
4. The urogenital system.
5. The circulatory system (including the lymphoid tissues and organs and the blood).
6. The nervous system and sense organs.
7. The skin and adnexa.
8. The ductless glands (exclusive of the thymus which is listed with the lymphoid organs).
9. A final unanalyzable group of general and unclassified publications.

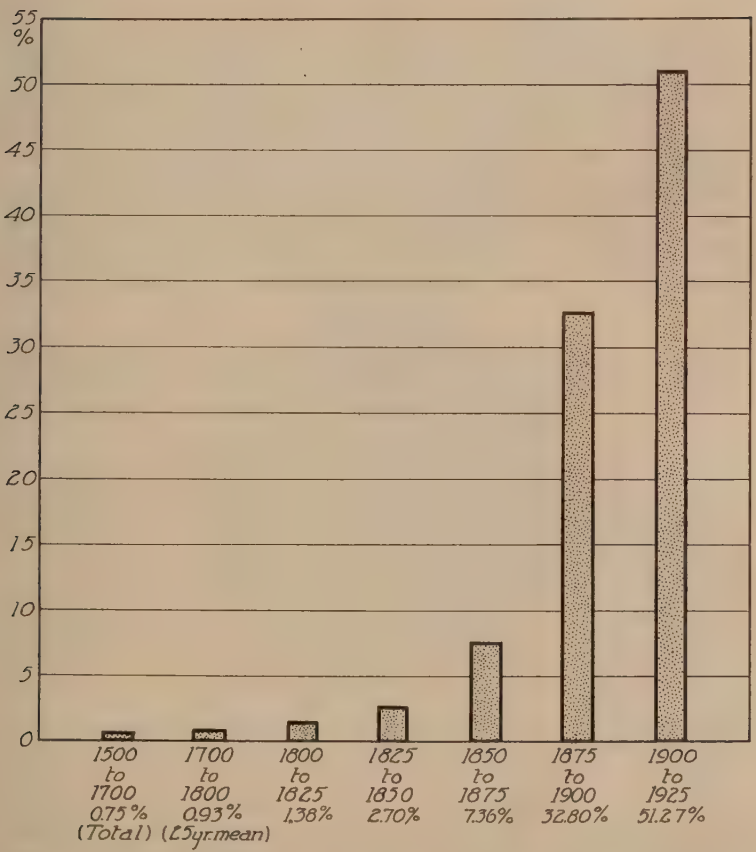

Fig. 1 A graph illustrating the distribution with respect to time of publications on the growth and physical development of the fetus, infant, and child.

The last category has been kept as small as possible and includes largely general discussions on the process of growth, the divisions of the developmental period, the technique of the study of physical development, the purely mathematical treatment of human growth, and the like. This classification of titles by subjects has been applied only to the material appearing after 1800, for most of the publications prior to this date are general in character and are chiefly of historic interest.

Table 2 and figure 2 illustrate this distribution of titles according to subject. Omitting the 4.4 per cent of the literature which appeared prior to 1800, we find that 1610, or about three-tenths of the total of listed publications, are concerned with general body growth. Following these come titles on the skeleton and the musculature and on the digestive and respiratory system, with 760 and 754 titles, respectively. The publications on each of these subjects, therefore, form approximately one-seventh of the listed literature in the

TABLE 2

Distribution of titles on growth and physical development according to subject

SUBJECT[1]	NUMBER OF TITLES	PER CENT OF TOTAL
1. General body growth	1610	30.02
2. Skeleton and musculature	760	14.17
3. Digestive and respiratory systems	754	14.06
4. Urogenital system	477	8.89
5. Circulatory system and lymphoid organs	637	11.87
6. Nervous system	385	7.18
7. Skin and adnexa	191	3.56
8. Ductless glands	141	2.62
9. General and unclassified	167	3.11
10. Ante 1800	240	4.47

[1] Detailed classification given in the text.

entire field. The literature on the circulatory system, the lymphoid organs, and the blood is represented by 637 titles, or slightly less than one-eighth of the whole. There are 477 titles on the urogenital system, or slightly less than 9 per cent of the total; while there are 385, or slightly over 7 per cent, on the nervous system and the organs of the special senses. One hundred and ninety-one, or about one-thirtieth of all titles, deal with the skin and its adnexa, and 141, or slightly over one-fortieth, are concerned with ductless glands. The category of general and unclassified titles contains 167 items, or a little over 3 per cent of the whole. The circle diagram shown in figure 2 illustrates this distribution graphically, the entire area of the circle representing 100 per cent, and the various segments, set off by special shading, the rela-

tive amount of literature by title in each division of the subject.

Table 3 shows the classification of this material by subject and by date for twenty-five-year intervals from 1800 to 1925, inclusive, and illustrates the trend of production in various parts of the field. Although the findings are somewhat conflicting, certain general changes are evident. The work on general body growth shows a marked lead in both relative and

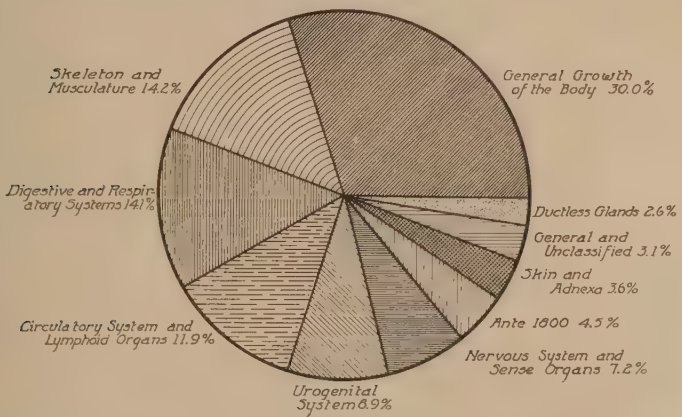
Skeleton and Musculature 14.2%
General Growth of the Body 30.0%
Digestive and Respiratory Systems 14.1%
Ductless Glands 2.6%
General and Unclassified 3.1%
Skin and Adnexa 3.6%
Ante 1800 4.5%
Circulatory System and Lymphoid Organs 11.9%
Nervous System and Sense Organs 7.2%
Urogenital System 8.9%

Fig. 2 A circle diagram illustrating the distribution, with respect to subject, of the publications on the growth and physical development of the fetus, infant, and child.

absolute number of titles in all of the time intervals. The more strictly anatomic work on the skeleton and the musculature reached both its absolute and its relative maximum in the last quarter of the nineteenth century, as did also the number of studies on the nervous system and sense organs. The relative number of publications on the circulatory system is variable, although there has been a steady increase with each quarter-century in the absolute number of titles on this subject. The same remark holds true for the titles on the digestive and respiratory and the urogenital systems. No separate titles on the ductless glands dating prior to 1850 are contained in this bibliography, but since that date papers

on the subject show a steady increase in both relative and absolute numbers. Titles on the skin and adnexa also show a marked absolute and relative increase. This is largely due in later years to the voluminous discussion on the 'Mongolian spot' in infancy. The relative number of general and unclassified titles shows a drop in the more modern periods, but this

TABLE 3

Distribution of titles on growth and physical development according to dates and subjects of publication. (The numbers in parentheses are the percentage frequencies of dates for subjects)

	GENERAL GROWTH OF BODY	SKELETON AND MUSCULATURE	CIRCULATORY SYSTEM AND LYMPHOID ORGANS	NERVOUS SYSTEM	DIGESTIVE AND RESPIRATORY SYSTEM	DUCTLESS GLANDS	UROGENITAL SYSTEM	SKIN	GENERAL AND UNCLASSED	TOTALS
1500–1600	....	....	....	....	....	....	....	....	....	11
1600–1700	....	....	....	....	....	....	....	....	....	30
1700–1800	....	....	....	....	....	....	....	....	....	199
1800–1825	21	12	12	4	9	....	9	....	7	74
	(28.4)	(16.2)	(16.2)	(5.4)	(12.2)		(12.2)		(9.5)	
1825–1850	42	14	39	4	26	....	12	2	6	145
	(29.0)	(9.7)	(26.9)	(2.8)	(17.9)		(8.3)	(1.4)	(4.1)	
1850–1875	129	96	43	22	48	2	37	7	11	395
	(32.7)	(24.3)	(10.9)	(5.6)	(12.2)	(0.5)	(9.4)	(1.8)	(2.8)	
1875–1900	518	283	201	182	242	28	202	44	59	1759
	(29.4)	(16.1)	(11.4)	(10.3)	(13.8)	(1.6)	(11.4)	(2.5)	(3.4)	
1900–1925	900	355	342	173	429	111	217	138	84	2749
	(32.7)	(12.9)	(12.4)	(6.3)	(15.6)	(4.0)	(7.9)	(5.0)	(3.1)	

change probably represents a more exact classification of the material on the part of the bibliographer rather than any real decrease in the number of publications in this category.

DISTRIBUTION OF TITLES WITH RESPECT TO LANGUAGE OF PUBLICATION

Table 4 and figure 3 show the distribution of titles in the field with respect to language of publication. Attention should be called to the fact that these figures do not accu-

rately represent either the nationality of the workers or the location of the investigations, for in many instances studies made in one country are published in another and in a different language. This is particularly true of the publications in German, for the excellent organization of the German scientific press has resulted in appearance of many publications from other nationalities in German journals. Studies from the Netherlands and from the Slavonic and Scandinavian countries, in particular, often appear in the German tongue. In recent years this is true to a lesser degree of English, since certain American journals have attracted articles written in English from the Latin-American countries. Again it has been necessary to adopt a somewhat arbitrary classification, which is as follows:

1. German.
2. French.
3. English.
4. Italian.
5. Latin.
6. Slavonic languages.
7. Scandinavian languages (Danish, Norwegian, and Swedish).
8. Spanish.
9. Dutch.
10. All others (including Hungarian, Portuguese, Japanese, and the artificial languages).

According to this classification, it is found that 2481, or about 46 per cent of all publications in this field, have appeared in German; French follows with 1084, or approximately 20 per cent; English contains 956, or nearly 18 per cent, and Italian 359, or nearly 7 per cent of the total.

Rather unexpectedly, it was found that 260, or nearly 5 per cent of all the publications on the list, were printed in Latin. These publications are composed to a large degree (nearly 80 per cent) of dissertation, brochures, and other separate publications which were issued prior to 1800. The last Latin publication in the bibliography bears the date of 1864.

Of the less widely distributed languages, the various Scandinavian tongues form the predominant group, containing some fifty titles, or about 1 per cent of the total. In no other language is the quota above 20. It is interesting to note that there have been several articles in Esperanto, particularly in recent Japanese journals.

Figure 4 shows, in contrast to figure 3, the distribution of titles by languages for material published prior to 1800. Of the papers in this period, over four-fifths were in Latin, about

TABLE 4

Distribution of titles on growth and physical development according to language of publication

LANGUAGE[1]	NUMBER OF TITLES	PER CENT OF TOTAL
German	2481	46.21
French	1084	20.21
English	956	17.82
Italian	359	6.69
Latin	260	4.84
Slavonic languages	121	2.25
Scandinavian languages	50	0.93
Spanish	19	0.35
Dutch	16	0.29
All others	16	0.29

[1] Detailed classification given in the text.

one-seventh in French, nearly one-thirtieth in English, and the remainder in Italian and German.

When the titles in bibliography are classified according to subject and according to language of publication, as shown in table 5, it is seen that, with one notable exception, the distribution of titles by language for the more generally used tongues in the various subdivisions in the field corresponds quite closely to the distribution by language in the subject as a whole. One striking exception is represented by the titles on general growth, which are more numerous in English than in French, and which probably represents the wide interest in the growth of children which has been notable of

recent years in this country and in Great Britain. Figure 5 shows this distribution of titles on general growth with respect to language of publication.

DISTRIBUTION OF TITLES WITH RESPECT TO TYPE OF PUBLICATION

One of the more interesting phases of this survey is the distribution of material with respect to type of publication. This distribution is a matter of practical importance, for it is the natural inference of most workers that the published

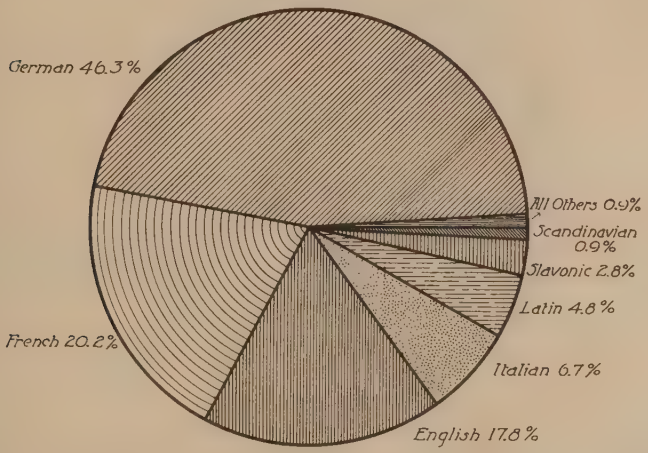

Fig. 3 A circle diagram illustrating the distribution, with respect to language of publication, of all listed titles on the growth and physical development of the fetus, infant, and child.

material in their field of investigation will be found mainly in the journals of that field. In fact, this rarely is the case. Publications of great importance in many branches of the subject are found in most unexpected places, and often under most misleading titles.

Ten subclasses have been recognized in the arrangement of this material according to types of publication. These are:

1. Periodicals of the medical sciences. This category includes the journals of anatomy, physiology, pathology, and pharmacology.

2. General medical periodicals, including both local medical journals, such as the various Wochenschriften, and also more general medical journals, such, for example, as the "American Journal of the Medical Sciences" and "Archives of Internal Medicine," in this country.

3. Pediatric periodicals, including both pediatric journals and the periodic publications and reports of pediatric institutes.

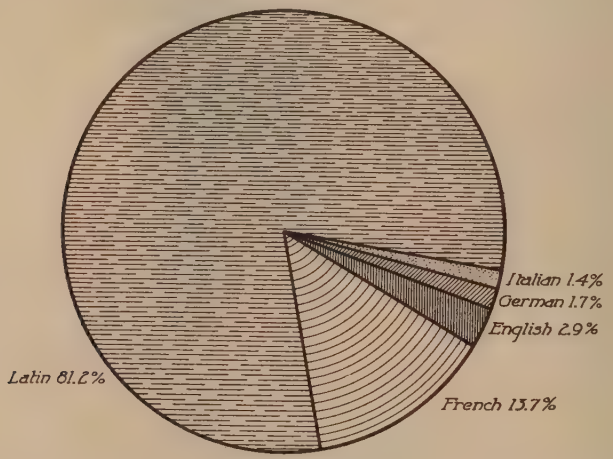

Fig. 4 A circle diagram illustrating the distribution, with respect to language, of titles dating prior to 1800 on the growth and physical development of the fetus, infant, and child.

4. Periodicals of obstetrics and gynecology and reports of institutions devoted to these subjects.

5. Periodicals of the medical specialties other than 3 and 4 above. This division is made up mainly of the special journals in clinical neurology, dermatology, and the diseases of the organs of special sense.

6. Periodicals devoted to anthropology and ethnology.

7. Periodicals of psychology and education.

8. General scientific periodicals, including journals such as "Science," "The Scientific Monthly," "Nature," "Revue Générale des Sciences," "Scientia," and "Globus," the

various reports and transaction of local and general learned societies, and general biological journals such, for example, as "Biometrika," "The Journal of Experimental Zoölogy," and the "Annales des Sciences Naturelles."

TABLE 5

Distribution of titles according to subject and to language of publication. (The numbers in parentheses are the percentage frequencies of languages for subjects)

	GERMAN	FRENCH	ENGLISH	ITALIAN	LATIN	SLAVONIC LANGUAGES	SCANDINAVIAN LANGUAGES	SPANISH	DUTCH	ALL OTHERS
General body growth	668 (41.5)	297 (18.4)	478 (29.7)	44 (2.7)	6 (0.4)	57 (3.5)	35 (2.2)	11 (0.7)	12 (0.7)	2 (0.1)
Skeleton and musculature	371 (48.8)	164 (21.6)	115 (15.1)	88 (11.6)	11 (1.4)	6 (0.8)	2 (0.3)	2 (0.3)	....	1 (0.1)
Digestive and respiratory	364 (48.3)	182 (24.1)	114 (15.1)	67 (8.9)	13 (1.7)	13 (1.7)	....	....	1 (0.1)	....
Urogenital system	272 (57.0)	101 (21.2)	45 (9.4)	35 (7.3)	8 (1.7)	11 (2.3)	4 (0.8)	....	1 (0.2)	....
Circulatory system and lymphoid organs	314 (49.3)	148 (23.2)	92 (14.4)	45 (7.1)	15 (2.4)	15 (2.4)	6 (0.9)	1 (0.2)	....	1 (0.2)
Nervous system	240 (62.3)	58 (15.1)	36 (9.4)	33 (8.6)	3 (0.8)	11 (2.9)	2 (0.5)	....	1 (0.3)	1 (0.3)
Skin and adnexa	107 (56.2)	40 (20.9)	17 (8.9)	7 (3.6)	1 (0.5)	2 (1.0)	1 (0.5)	4 (2.1)	1 (0.5)	11 (5.8)
Ductless glands	74 (52.4)	22 (15.6)	12 (8.5)	29 (20.6)	....	4 (2.8)	....	....	....	....
General and unclassed	67 (40.1)	39 (23.4)	40 (23.9)	10 (6.0)	8 (4.8)	2 (1.2)	....	1 (0.6)	....	....
Ante 1800	4 (1.7)	33 (13.8)	7 (2.9)	1 (0.4)	195 (81.2)	....	....	....	....	....

9. Theses and dissertations.

10. Separate publications other than 9 above.

Table 6 and figure 6 show this distribution with respect to type of publication. Periodicals of the medical sciences lead in this classification, for they contain 1198, or something over 22 per cent of all the listed titles. General medical periodicals have a quota almost equally large, there being 1040, or

over 19 per cent of the total in this category. Theses and dissertations form the third group in size, with 684, or nearly 13 per cent of all titles, and this is closely approached by other separate publications, in the form of books, pamphlets and brochures, which contain 642, or nearly 12 per cent of the total number of items. The pediatric literature, which a priori might be expected to be the richest source of material of this sort, contains 430, or about 8 per cent of the total. General scientific periodicals and the reports of learned

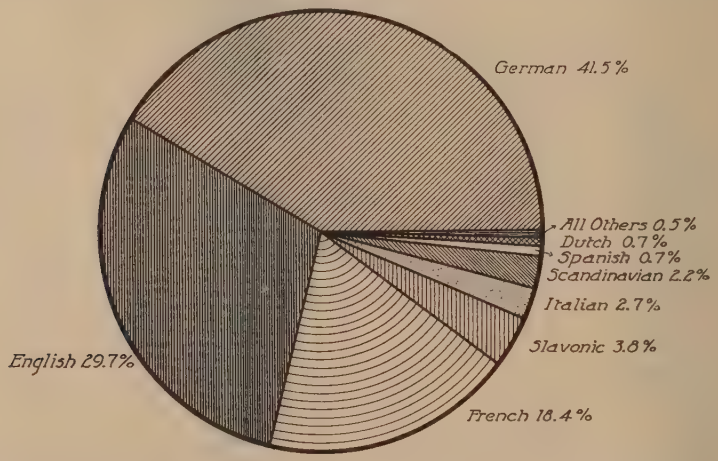

Fig. 5 A circle diagram illustrating the distribution, with respect to language of publication, of titles on the general growth of the fetus, infant, and child.

societies and academies contain nearly 400, or somewhat over 7 per cent of the total, and the number and proportion of articles in the obstetric and gynecological literature is approximately the same. The periodicals of the medical specialties, according to the classification given in the preceding paragraph, contain 234, or somewhat over 4 per cent of the total number of listed articles. Most of these are to be found in the journals of ophthalmology and otolaryngology. The various anthropological publications are represented by 201 papers. They form 3.74 per cent of the total. The periodicals devoted to psychology and education contain 147 titles, or 2.74 per cent of the total.

Table 7 and figures 7, A, to 7, I, inclusive, show the relative distributions of the titles forming each of the ten subdivisions in the field of growth and physical development, with respect to the ten classes of publications tabulated above.

Of all the listed titles dealing with the general growth of the body, 23.4 per cent, or nearly one-quarter, are located in general medical journals. Between one-eighth and one-seventh are to be found in each of the following classes of publication; periodicals of pediatrics, periodicals of obstetrics and gynecology, theses and dissertations, and separate

TABLE 6

Distribution of titles on growth and physical development according to type of publication

TYPE OF PUBLICATION[1]	NUMBER OF TITLES	PER CENT OF TOTAL
1. Medical sciences	1198	22.34
2. General medical	1040	19.39
3. Pediatrics	430	8.01
4. Obstetrics and gynecology	392	7.31
5. Medical specialties	234	4.36
6. Anthropology	201	3.74
7. Psychology and education	147	2.74
8. General scientific	394	7.34
9. Theses and dissertations	684	12.75
10. Separate publications	642	11.97

[1] Detailed classification given in text.

publications. Somewhat more than one-twelfth have appeared in the journals of psychology and education and a slightly smaller proportion in general scientific periodicals. The journals devoted to the fundamental medical sciences contain only about one-fourteenth of this material.

Nearly one-third of the listed papers on the skeleton and musculature are to be found in periodicals of the medical sciences. Between one-sixth and one-fifth have appeared in general medical journals. Over one-tenth of the total on this phase of the subject are located in general scientific periodicals, about an equal portion are in the form of theses

or dissertations, and a slightly smaller number is composed of other separate publications.

The journals of the fundamental medical sciences contain nearly one-third of all listed studies on the digestive and respiratory systems, and the general medical journals over one-fifth. Theses and dissertations make up about one-thirteenth of the studies on this subject. The journals of pediatrics, of the medical specialties, and of general science,

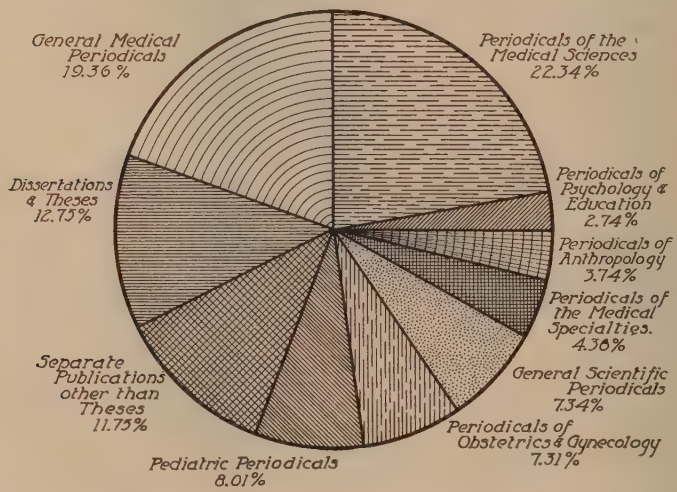
General Medical Periodicals 19.36%
Periodicals of the Medical Sciences 22.34%
Periodicals of Psychology & Education 2.74%
Periodicals of Anthropology 3.74%
Periodicals of the Medical Specialties. 4.36%
General Scientific Periodicals 7.34%
Periodicals of Obstetrics & Gynecology 7.31%
Pediatric Periodicals 8.01%
Separate Publications other than Theses 11.73%
Dissertations & Theses 12.75%

Fig. 6 A circle diagram illustrating the distribution, with respect to types of publication, of titles on the growth and physical development of the fetus, infant, and child.

and separate publications other than theses, each contain between one-sixteenth and one-twelfth of the total.

Over one-third of the listed titles on the urogenital system are in the journals of the medical sciences, about one-fifth in periodicals devoted to obstetrics and gynecology, and between one-sixth and one-seventh in more general medical journals. Theses and dissertations form one-eighth of these titles, and other separate publications about one-fourteenth.

The periodicals of the medical sciences contain between one-quarter and one-third of the listed publications on the circu-

latory system and lymphoid organs, and the general medical journals between one-fifth and one-quarter. Theses and dissertations form nearly one-sixth of this material, and the publications in pediatric journals a slightly smaller proportion.

Of the listed titles on the nervous system between one-quarter and one-third come from the periodicals of the medical sciences, one-fourth from the journals of the medical specialties, and about one-seventh from the general medical journals. Approximately one-ninth are in the form of theses or dissertations, and about one-eleventh in other separate publications. The remaining titles are irregularly scattered through the other types of publication.

Approximately one-fifth of the listed titles on the skin and adnexa are located in the pediatric journals, about equal proportions in the journals of the various medical sciences, and nearly as many in general medical periodicals. Nearly one-sixth are found in the anthropological journals, and nearly one-twelfth have appeared as theses or dissertations.

Over one-half of the listed articles on the ductless glands appeared in the periodicals of the fundamental medical sciences and about one-fifth in general medical journals. Approximately one-eleventh are in the form of theses and dissertations, one-eighteenth in the form of articles in general scientific periodicals, and one-twentieth in the form of separate publications.

Of the general and unclassed titles in the bibliography, nearly one-quarter are in the form of articles in the journals of the medical sciences. One-fifth have appeared in separate publications, and one-ninth as theses or dissertations. Approximately one-seventh are in the general medical journals, and approximately one-eighth in the pediatric journals.

This analysis indicates that, general growth excepted, the journals of the medical sciences are the first source for material on the various phases of growth and physical development in the fetal period, infancy, and childhood. The next source in order of importance is the periodic literature of

general medicine, and the third, in the majority of instances, consists of theses and dissertations. The order of frequencies of the various types of publication following these three is extremely irregular, varying with the subdivision of the field considered. However, it should be noted that this analysis

TABLE 7

Distribution in different types of publications of titles on various phases of growth and physical development. (The numbers in parentheses are percentage frequencies of titles in each class of publication in each subject)

	MEDICAL SCIENCES	GENERAL MEDICAL	PEDIATRICS	OBSTETRICS AND GYNECOLOGY	MEDICAL SPECIALTIES	ANTHROPOLOGY	PSYCHOLOGY AND EDUCATION	GENERAL SCIENTIFIC	THESES AND DISSERTATIONS	SEPARATE PUBLICATIONS
General body growth	113 (7.0)	376 (23.4)	190 (11.8)	183 (11.4)	2 (0.1)	92 (5.7)	142 (8.8)	132 (8.2)	198 (12.3)	182 (11.3)
Skeleton and musculature	229 (30.1)	137 (18.0)	18 (2.4)	30 (3.9)	40 (5.3)	55 (7.2)	....	86 (11.3)	85 (11.2)	80 (10.5)
Digestive and respiratory	241 (32.0)	167 (22.1)	57 (7.6)	20 (2.7)	64 (8.5)	6 (0.8)	1 (0.1)	45 (6.0)	100 (13.3)	53 (7.0)
Urogenital system	169 (35.4)	73 (15.3)	4 (0.8)	98 (20.5)	12 (2.5)	2 (0.4)	....	23 (4.8)	61 (12.8)	35 (7.3)
Circulatory system and lymphoid organs	185 (29.0)	143 (22.4)	86 (13.5)	35 (5.5)	4 (0.6)	2 (0.3)	....	39 (6.1)	99 (15.5)	44 (6.9)
Nervous system	110 (28.6)	55 (14.3)	10 (2.6)	3 (0.8)	95 (24.7)	10 (2.6)	2 (0.5)	23 (6.0)	44 (11.4)	33 (8.6)
Skin and adnexa	40 (20.9)	36 (18.8)	39 (20.4)	7 (3.7)	9 (4.7)	30 (15.7)	....	12 (6.3)	15 (7.9)	3 (1.6)
Ductless glands	72 (51.1)	27 (19.1)	6 (4.3)	3 (2.1)	5 (3.5)	....	....	8 (5.7)	13 (9.2)	7 (5.0)
General and unclassed	39 (23.4)	25 (14.4)	20 (12.0)	13 (7.8)	3 (1.8)	4 (2.4)	2 (1.2)	8 (4.8)	19 (11.4)	34 (20.4)

is based upon the number of publications only, without regard to their length or content, and that a consideration of the latter factors might modify this ranking.

Table 8 shows a less important classification, namely, the distributions of titles, with regard to subject, in each type of publication. As might be expected, there is a marked variability in these distributions in several classes of literature.

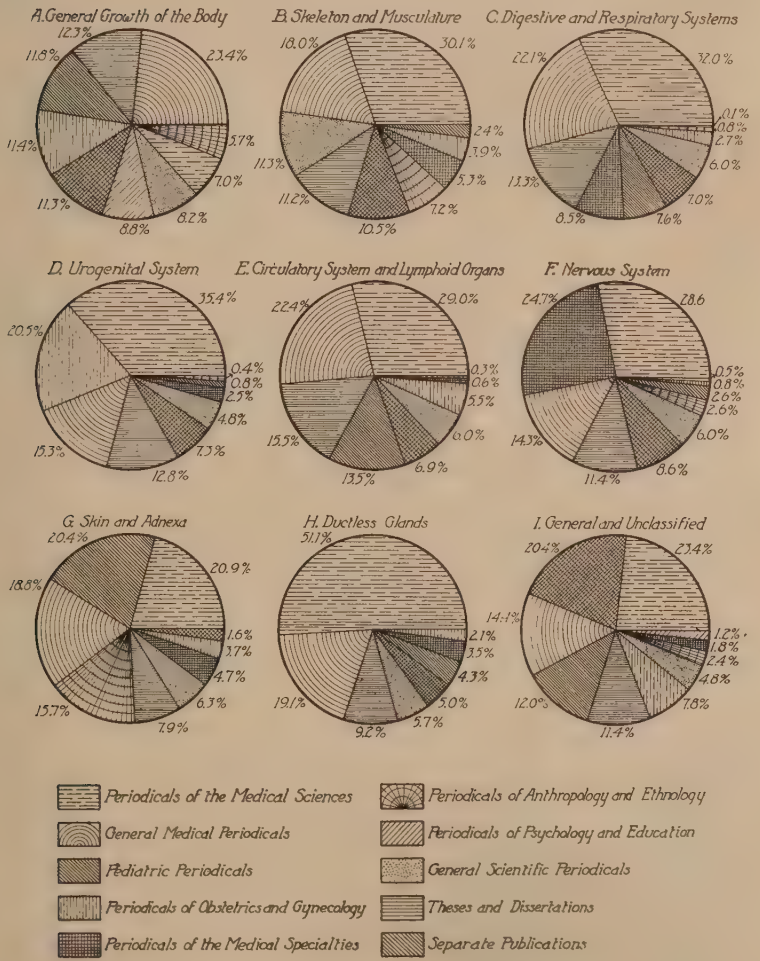

Fig. 7 A series of circle diagrams illustrating the distributions, with respect to types of publication, of the titles in nine main subdivisons of the subject of the growth and physical development of the fetus, infant, and child.

Of all the titles collected from the journals of the medical sciences, approximately one-fifth deal with the skeleton and musculature and about an equal proportion with the digestive and respiratory systems. Approximately one-seventh are concerned with the urogenital system and a slightly larger

TABLE 8

Distribution of titles on growth and physical development according to subject and type of publication. (The numbers in parentheses are the percentage frequencies of subjects in publications)

	GENERAL BODY GROWTH	SKELETON AND MUSCULATURE	DIGESTIVE AND RESPIRATORY	UROGENITAL SYSTEM	CIRCULATORY SYSTEM AND LYMPHOID ORGANS	NERVOUS SYSTEM	SKIN AND ADNEXA	DUCTLESS GLANDS	GENERAL AND UNCLASSED
Medical sciences	113 (9.4)	229 (19.1)	241 (20.1)	169 (14.1)	185 (15.4)	110 (9.2)	40 (3.3)	72 (6.0)	39 (3.3)
General medical	376 (36.2)	137 (13.2)	167 (16.1)	73 (7.0)	143 (13.8)	55 (5.3)	36 (3.5)	27 (2.6)	25 (2.4)
Pediatrics	190 (44.2)	18 (4.2)	57 (13.3)	4 (0.9)	86 (20.0)	10 (2.3)	39 (9.1)	6 (1.4)	20 (4.7)
Obstetrics and gynecology	183 (46.7)	30 (7.7)	20 (5.1)	98 (25.0)	35 (8.9)	3 (0.8)	7 (1.8)	3 (0.8)	13 (3.3)
Medical specialties	2 (0.9)	40 (17.1)	64 (27.4)	12 (5.1)	4 (1.7)	95 (40.6)	9 (3.8)	5 (2.1)	3 (1.3)
Anthropology	92 (45.8)	55 (27.4)	6 (3.0)	2 (1.0)	2 (1.0)	10 (5.0)	30 (14.9)	....	4 (2.0)
Psychology and education	142 (96.6)	....	1 (0.7)	....	....	2 (1.4)	....	....	2 (1.4)
General scientific	132 (35.1)	86 (22.9)	45 (12.0)	23 (6.1)	39 (10.4)	23 (6.1)	12 (3.2)	8 (2.1)	8 (2.1)
Theses and dissertations	198 (31.2)	85 (13.5)	100 (15.8)	61 (9.6)	99 (15.6)	44 (6.9)	15 (2.4)	13 (2.1)	19 (3.0)
Separate publications	182 (38.6)	80 (17.0)	53 (11.3)	35 (7.4)	44 (9.3)	33 (7.0)	3 (0.6)	7 (1.5)	34 (7.2)

fraction with the circulatory system and lymphoid organs. The number of titles on the nervous system forms slightly less than one-tenth of the total, as does also the number on general growth of the body. Six per cent of the references obtained from this class of publication deal with the ductless glands (exclusive of the thymus which has been grouped with the lymphoid organs).

Over one-third of all the titles from the general medical periodicals are devoted primarily to the discussion of the general growth of the body, about one-sixth to the digestive and respiratory tracts, slightly less than one-seventh to the skeleton and musculature, an equal proportion to the circulatory system and lymphoid organs, about one-fourteenth to the urogenital system, and about one-twentieth to the nervous system. The remainder consists of unclassed titles and titles on the skin and ductless glands.

Of the titles contained in the journals of pediatrics, over two-fifths deal with the general growth of the body, one-fifth with the circulatory system and lymphoid organs, between one-eighth and one-seventh with the digestive and respiratory tracts, and one-eleventh with the skin and its adnexa. The remainder are scattered irregularly through the other divisions of the field.

Of the titles listed from the periodic literature of obstetrics and gynecology, between two-fifths and one-half are on the general growth of the body (mainly the growth of the fetus and the weight and dimensions of the newborn), one-quarter are on the urogenital system, about one-eleventh on the circulatory system and lymphoid organs (particularly the fetal circulation and its changes at birth), and one-thirteenth on the skeleton.

About two-fifths of the papers listed from the periodicals devoted to the medical specialties are on the nervous system and the special sense organs. Over one-fifth deal with the digestive and respiratory systems (consisting mainly of studies on the nose and paranasal sinuses, the tonsils, the pharynx, and the larynx). Over one-sixth deal with the skeleton and musculature (consisting almost exclusively of articles dealing with the muscles of the orbit, the orbital and nasal skeleton, and the temporal bone). The remainder of the titles are rather generally scattered through the other subdivisions of the field.

Between two-fifths and one-half of the titles of articles contained in the anthropological periodicals deal with the

general growth of the body, over one-quarter with the skeleton and musculature, over one-seventh with the skin (almost exclusively with the 'Mongolian spot'), and one-twentieth with the nervous system.

Almost all (96.6 per cent) of the titles obtained from the periodicals devoted to psychology and education deal with the general growth of the body. Of the remaining items (five only) two are unclassed, two are concerned with the central nervous system and one with the digestive tract.

Over one-third of the references listed from general scientific periodicals have to do with general body growth, and over one-fifth with the skeleton and musculature. About one-eighth deal with the digestive and respiratory tract, and about one-tenth with the circulatory system and lymphoid organs. The references dealing with the urogenital system and with the nervous system each form about one-sixteenth of the total listed from this type of publication.

Of the theses and dissertations listed in this bibliography somewhat less than one-third are on the general growth of the body. Slightly less than one-sixth deal with the digestive and respiratory tracts, and about an equal proportion with the circulatory system and lymphoid organs. Between one-eighth and one-seventh are concerned with the skeleton and musculature, about one-tenth with the urogenital system, and about one-fourteenth with the nervous system. Titles on the skin and adnexa form about one-fortieth, and those on the ductless glands about one-fiftieth of the total number of theses.

Nearly two-fifths of the separate publications (other than theses and dissertations) listed in this bibliography describe the general growth of the body. Slightly over one-tenth are devoted to the digestive and respiratory tracts, and somewhat less than one-tenth to the circulatory system and lymphoid organs. Titles on the urogenital system, the nervous system, and general and unclassed references, each form about one-fourteenth of these separate publications.

RELIABILITY OF INDEX AND REVIEW JOURNALS AS A SOURCE OF LITERATURE ON GROWTH AND PHYSICAL DEVELOPMENT

Since one commonly first turns to review and abstract journals in securing bibliographic material, it seemed worth while to make a limited test of the efficiency of these publications in listing the literature on the subject under consideration. The years 1910, 1911, and 1912 were chosen for this test, for it was thought best to select a period prior to the disorganization in the scientific literature caused by the war. The titles for these three years, amounting to a total of 392, were taken from the bibliography and were checked in six bibliographic sources, namely, the "Jahresberichte über die Fortschritte der Anatomie und Entwicklungsgeschichte," the "Zentralblatt für normale Anatomie und Mikrotechnik," the "Index Medicus," the "Zentralblatt für Anthropologie," the "Zentralblatt für Kinderheilkunde," and the "Referate" of the "Zeitschrift für Kinderheilkunde." In the last publication the references were limited to the year 1912, when this journal began publication. In each instance the titles for each given year were checked not only in the volume of the journal for that year, but also in those of the two succeeding ones, so that any delayed references might be credited. The results of this analysis are shown in table 9 and figure 8. The "Jahresberichte über die Fortschritte der Anatomie" was the most successful in obtaining this material, for it lists 190 of the 392 titles in the bibliography for the three-year period, or slightly over 48 per cent. The "Index Medicus" listed somewhat over 46 per cent of all the titles for the three-year period, although it secured less than one-third of those appearing in 1910. The "Zentralblatt for Anthropologie" listed but ten of the 392 titles, or 2.55 per cent, or approximately one-fortieth of the total. The "Zentralblatt für Kinderheilkunde" was a little more complete, for it secured twenty of the total number of titles in the bibliography for this period—a proportion of 5.1 per cent, or about one-twentieth of the whole. In the single year for which the "Referate" of the "Zeitschrift für Kinderheilkunde" was

available, this publication gave notices or abstracts of thirty-four articles in the field, or 26.36 per cent, or slightly over one-quarter of the total number of titles in the bibliography for this period.

As a final check the number of listed titles for these years in all of the six journals were combined, the duplications eliminated, and the net total placed in the form of a per-

TABLE 9

Per cent and number of titles on growth and physical development listed in six standard review journals for the years 1910 to 1912, inclusive

Year of publication		1910	1911	1912	1910, 1911, and 1912
Total number of titles in bibliography		136	127	129	392
Titles in Jahresberichte über die Fortschritte der Anatomie und Entwicklungsgeschichte	Number	70	69	51	190
	Per cent	51.47	54.33	39.53	48.47
Titles in Zentralblatt für normale Anatomie und Mikrotechnik	Number	44	38	19	101
	Per cent	32.35	29.92	14.73	25.77
Titles in Index Medicus	Number	41	73	68	182
	Per cent	30.15	57.48	52.71	46.43
Titles in Zentralblatt für Anthropologie	Number	3	6	1	10
	Per cent	2.21	4.72	0.78	2.55
Titles in Zentralblatt für Kinderheilkunde	Number	8	6	6	20
	Per cent	5.88	4.72	4.65	5.10
Titles in Zeitschrift für Kinderheilkunde-Referate	Number	....	....	34	....
	Per cent	....	....	26.36	....
Total of listed titles in above (duplications omitted)	Number	106	104	97	307
	Per cent	77.94	81.89	75.19	78.32

centage of the total number of titles for this period in the bibliography. The ratios thus obtained range from about 75 to about 82, with an average of 78.32 per cent, or between three-fourths and four-fifths of the total listed in this bibliography.

These results were somewhat surprising, particularly in regard to the review journals in pediatrics and the "Index Medicus." It is hoped that the new "Biological Abstracts"

will supplement review journals of this type in presenting a more complete summary of the literature in this field.

PUBLISHED BIBLIOGRAPHIES ON GROWTH AND PHYSICAL DEVELOPMENT

Although no substantially complete bibliography of the literature in all branches of this field has been published, there are a number of bibliographic sources of considerable value. The following annotated list includes some of the more important of these bibliographies.

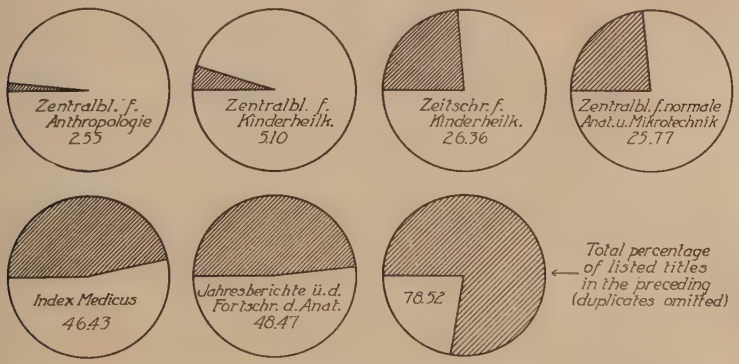
Zentralbl. f. Anthropologie 2.55
Zentralbl. f. Kinderheilk. 5.10
Zeitschr. f. Kinderheilk. 26.36
Zentralbl. f. normale Anat. u. Mikrotechnik 25.77
Index Medicus 46.43
Jahresberichte ü. d. Fortschr. d. Anat. 48.47
78.52
Total percentage of listed titles in the preceding (duplicates omitted)

Fig. 8 A series of circle diagrams illustrating the percentage of titles on the growth and physical development of the fetus, infant, and child appearing in the year 1910 to 1912, inclusive, which were listed in six standard review and abstract journals in the years 1910 to 1913, inclusive.

BIBLIOGRAPHY

BALDWIN, B. T. 1921 The physical growth of children from birth to maturity, University of Iowa Studies in Child Welfare, vol. 1, no. 1, 411 pp.

Includes a very complete and carefully annotated bibliography of 911 titles on physical growth from birth to maturity. The most complete published source of material on this phase of the subject.

CZERNY, A., AND KELLER, A. 1925 Des Kindes Ernährung, Ernährungsstörungen und Ernährungstherapie. Zweite Aufl., Bd. 1. Berlin.

An extensive bibliography of general growth is included at the close of chapter V (''Die Vorgänge im Stoffwechsel während der ersten Lebenstage''), pp. 319–333, and in the footnotes to chapter XV (''Längen- und Gewichtswachstum vom Säuglingsalter bis zum Abschluss der Pubertät''), pp. 772–884.

FELDMAN, W. M. 1920 The principles of ante-natal and postnatal child physiology pure and applied.

Numerous bibliographic references in the form of footnotes.

GUNDOBIN, N. P. 1911 Die Besonderheiten des Kindesalters. (German translation by S. Rubinstein and Langstein from the original Russian work published in 1907.) XX + 592 pp. Berlin.

Excellent bibliographic lists at the close of each chapter and abstracts of a large amount of Russian work which is otherwise almost inaccessible. This material includes some 2200 titles, the majority of which refer to physical growth and development.

HENKE, W. 1881 Anatomie des Kindesalters. In Handbuch der Kinderkrankheiten, C. Gerhardt, Ed., Zweite Aufl., Bd. 1, Erste Abt., pp. 77–203. Tübingen.

This summary contains bibliographies of some of the more important earlier studies. Skeleton and adnexa, pp. 79–80; viscera and vascular system, p. 163. The bibliography in the second edition (1881) is more complete than that in the first (1878).

"L. HN." 1878 (A bibliography appended to the articles of Pinard, entitled: "Foetus. Anatomie et physiologie." In Dictionnaire Encyclopédique des Sciences Médicales, Sér. 4., T. 2, pp. 526–535.)

This is probably the best single bibliography of older literature on the anatomy and growth of the human fetus. It contains some 400 titles of publications prior to 1878, including a number dating from the seventeenth and eighteenth centuries. Evidently the bibliography was not compiled by Pinard, but by "L. Hn.," whose initials are appended to this, as well as to a number of other literature lists in this work.

METTENHEIMER, H. 1893 Ein Beitrag zur topographischen Anatomie der Brust, Bauch und Beckenhöhle des neugenborenen Kindes. Morphol. Arbeiten Bd. 3, pp. 301–398.

Contains a large number of references on developmental topography in infancy.

ROBERTSON, T. B. 1923 The chemical basis of growth and senescence. VIII + 389 pp. Philadelphia and London.

The general bibliography at the close of this book contains a number of references to studies on the more modern phases of the problem of human growth.

RÖSSLE, R. 1923 Wachstum und Altern. Zur Physiologie und Pathologie der postfötalen Entwicklung. IV + 351 pp. München.

The first section of this work, on normal development, includes a well-selected bibliography of 493 titles, a large number of which deal with human growth.

SCAMMON, R. E. 1923 A summary of the anatomy of the infant and child. In Pediatrics, by various authors, I.A.Abt, ed., vol. 1, chapter III (pp. 257–444). Philadelphia.

Contains a selected bibliography of 377 references to work in this field, exclusive of the general growth of the body.

SCHLESINGER, E. 1926 Das Wachstum des Kindes. 128 pp. Berlin.

A well-selected bibliography of some 300 titles containing references to many recent German papers.

VIERORDT, H. 1906 Anatomische, physiologische und physikalische Daten und Tabellen. VI + 616 pp., Dritte Aufl. Jena.

Extensive bibliography on the quantitative phases of human growth, in the form of footnotes scattered through the volume.

VIERORDT, K. 1881 Physiologie des Kindesalters. In Handbuch der Kinderkrankheiten, C. Gerhardt, ed., zweite Aufl., Bd. 1, Erste Abt., pp. 219–220, 290–291, 298, 302, 322, 327–328, 387. Tübingen.

Contains a large number of references, which are often missed, to the older material. The bibliography in the second edition (1881) is more complete than that in the first (1878).

THE TECHNIQUE OF DETERMINING IRREGULAR AREAS IN MORPHOLOGICAL STUDIES

RICHARD E. SCAMMON AND GORDON H. SCOTT
Department of Anatomy and Institute of Child Welfare, University of Minnesota

TWO FIGURES

Investigators in the field of quantitative morphology frequently encounter the technical problem of the determination of areas with irregular outlines. The diversity of the studies in which this problem enters is surprising. Among them may be mentioned the determination of the surface area of the body, the area of tissue cultures, the changes in wound area during the process of healing, the involution of the fontanelles, the form changes in bacteria at different phases in their growth cycles, the progress of carpal ossification in childhood, and the quantitative analysis of the structural composition of various organs.

A number of methods have been used in connection with this problem. In a few instances recourse has been had to graphical integration methods by measurements of component strips of the area, by the application of some of the simpler approximation formulae, such as the 'rectangular,' 'trapezoidal,' or 'Simpson's rule,' or by counting the enclosed squares when the area is laid out on coordinate paper.[1] The last procedure was used by Nikiforoff ('00) in the study of the involution of the frontal fontanelle and by Dargein ('99) in the determination of the mucosal area of the stomach and duodenum. These methods are now largely supplanted by the mechanical ones discussed in the following paragraphs.

[1] For a discussion of approximate integration methods, see Lipka ('18, p. 224 et seq.) and von Sanden ('14, p. 102 et seq.).

THE PLANIMETRIC METHOD

A large number of studies of area has been made with the aid of the Amsler polar planimeter.[2] As examples there may be cited the work of Anton ('03) and Jaeger ('10) on the mass of the cerebral cortex, of Baldwin ('23) and of Freeman and Carter ('24) on carpal area, of Pfaundler ('16) on the surface area of infants, of Scammon ('15) on the vascular area of the developing liver, and of Laurell (quoted by Hammar, '15) on the thymus. However, most careful students have found that this instrument is far from satisfactory for the purpose at hand. It is subject to error through the personal equation in directing the tracing point, through irregularities in the movement of the integrating wheel and through certain factors in the mechanical adjustment of the working parts of the instrument. The latter errors, which are relatively small, have been studied by several workers (Henrici, '94) and hardly need further investigation. However, the gross error, including the first or personal one, is of practical importance in the problem at hand, and we therefore tested it with a 7-inch Amsler planimeter (made by Coradi) in the following manner:

Circles of various sizes were drawn in fine ink-line on smooth 'Bristol board' and the instrument set up for use so that its integration wheel passed over a smooth wooden surface covered with bond paper. Twenty-five consecutive readings were then taken of each circle by one observer by passing the index pointer about its circumference. The apparatus was so arranged that the person making the measurement could not see the resulting readings, which were recorded independently by a second operator to avoid the psychological element. Table 1 gives our findings for circles ranging from approximately 1 cm. to 4 cm. in diameter. It will be noted that the probable error of the mean is about 1.5 sq.mm. in all of the tests except the one for the first or smaller circle, where it is slightly less than 1 sq.mm. Consequently, the

[2] Possibly other types of planimeters have been used as well, but the polar form is the one commonly employed.

coefficients of variability are much greater for the smaller than the larger disks, ranging from over 8.3 per cent for the circle with an approximate diameter of 1 cm. to 0.84 per cent for the largest circle having a diameter of approximately 4 cm. These errors are too large to be disregarded in quantitative work, and they indicate that a more precise method for determining area is desirable.

THE AREA-BY-WEIGHT METHOD

The area-by-weight method was introduced by Hammar who used it extensively in the study of the thymus and described it in detail in a special paper (Hammar, '15). He

TABLE 1

Variabilities of serial planimetric determinations of areas of circles of different diameters

DISC NO.	NUMBER OF OBSERVATIONS	APPROXIMATE DIAMETER OF DISC	CALCULATED AREA	AVERAGE OBSERVED AREA	STANDARD DEVIATION	COEFFICIENT OF VARIABILITY
		cm.	*sq.cm.*	*sq.cm.*	*sq.cm.*	*per cent*
I	25	1.00	0.785	0.760±0.009	0.063±0.006	8.328±0.794
II	25	1.85	2.686	2.464±0.015	0.109±0.010	4.428±0.422
III	25	2.00	3.142	3.004±0.016	0.119±0.011	3.961±0.378
IV	25	3.00	7.069	6.852±0.014	0.106±0.010	1.544±0.147
V	25	4.00	12.566	12.320±0.014	0.104±0.010	0.843±0.080

sectioned the thymus serially, projected the section on heavy, well-made paper ('Dokumentpapier'), traced them, cut out their various areas, and weighed each. He then computed the area from the weight of the paper by determining a weight-area ratio by weighing a sample of the paper of known area.[3] This method has been extensively employed for the quantitative analysis of the structural components of various organs by Jackson ('17), Rasmussen ('22, '24), Atwell and Woodworth ('26), and others.

There seem to be three chief sources of error in the area-by-weight method when paper is employed: First, those in-

[3] Hammar used wax plates in his earlier work on this problem.

volved in cutting out the elaborate outlines of various structures; secondly, the variability in moisture content, and therefore in weight-area ratio of the paper, and, thirdly, variations in the thickness of the individual sheets of the paper stock used in the study. The first error is small in the hands of a careful operator and can hardly be entirely obviated by any method. The error of moisture content is a very real one and should be taken in consideration whenever this method is employed. A number of studies on this subject have appeared in the technical journals of the paper trade, among the more important being those of Campbell ('21), Curtis ('21), and Houston, Carston, and Kirkwood ('23). It has been shown that there is a rapid, though not constant, absorption of water by both ledger and bond papers with increasing atmospheric humidity. There is also a change in the area of the paper due to its expansion with the increase of moisture in the air. Figures 1 and 2 are curves showing the change in weight of bond and ledger papers, such as are used in this method, with increasing humidity. They are drawn from the data given by Houston, Carston, and Kirkwood.

Part of the difficulty of moisture absorption can be avoided by using Atwell and Woodworth's technique of storing the paper cuttings for a week in a desiccator and weighing them upon removal. However, the weighing should be carried out immediately after removal of the paper from the desiccator, for the unpublished studies of Miller have shown that print paper, at least, absorbs a large per cent of its final moisture content within twenty minutes after exposure to the air, and the greater part within forty-five minutes.

The variability in thickness in various parts of sheets of commercial bond paper is also hardly negligible. To test this factor we have used large sheets of the paper employed in this laboratory for the area-weight method, which is known as 'Resolute Ledger, no. 32.' These sheets were placed on a firm surface, and fifty disks having a diameter of approximately 1.8 cm. were punched from them at random with a

hollow steel cylinder whose lower margin was ground to a knife edge. A similar set of disks, fifty in number, approximately 4 mm. in diameter, were cut in the same manner. These disks were then weighed on a delicate analytical balance. To obviate as far as possible the psychological element in this

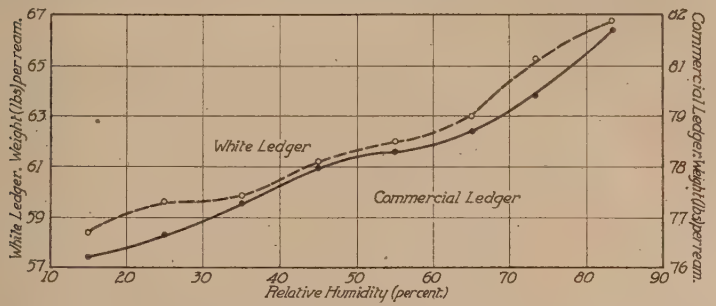

Fig. 1 Curves showing the gain in weight of bond paper with increasing relative humidity. Based upon the data of Houston, Carston, and Kirkwood ('23).

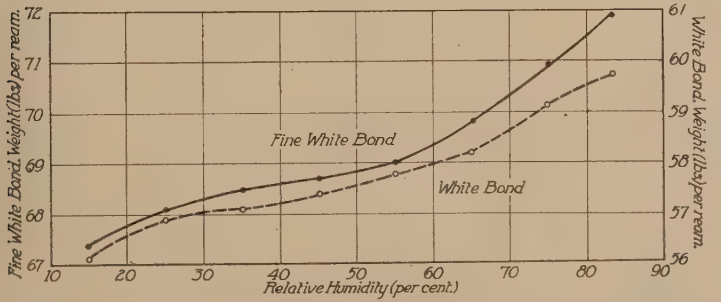

Fig. 2 Curves showing the gain in weight of ledger paper with increasing relative humidity. Based upon the data of Houston, Carston, and Kirkwood ('23).

experiment, two observers were employed in making the weighings, one adjusting the analytic balance used, while the other, a totally disinterested party, recorded each weight. Twenty-five weighings were made each day and each object was weighed to the nearest ten-thousandth of a gram. No attempt was made to control external conditions other than to brush any free dust from the paper and to handle the disks

with forceps to avoid any undue addition of moisture from the fingers. The first, second, fifth, and sixth rows of figures in table 2 give the findings obtained on these disks. They show that the coefficients of variability lie between 2 and 2.5 per cent for the larger disks and in the neighborhood of 3 per cent for the smaller ones.

TABLE 2

Variabilities of weighings of series of paper and celluloid disks

ITEM	NUMBER OF OBSERVATIONS	MEAN VALUE	STANDARD DEVIATION	COEFFICIENT OF VARIABILITY	NOTES
		mg.	*mg.*	*Per cent*	
Large paper disks (a)	25	30.67±0.103	±0.767±0.073	2.50±0.239	H.[1] 82 %; T.[2] 73.2°
Large paper disks (b)	25	30.22±0.089	±0.657±0.063	2.17±0.207	H. 49 %; T. 69.7°
Large celluloid disks (a)	25	51.44±0.021	±0.158±0.015	0.31±0.296	H. 42 %; T. 87.5°
Large celluloid disks (b)	25	51.40±0.023	±0.167±0.016	0.33±0.315	H. 56 %; T. 85.2°
Small paper disks (a)	25	1.53±0.006	±0.044±0.004	2.85±0.272	H. 88.2%; T. 62.0°
Small paper disks (b)	25	1.52±0.007	±0.048±0.005	3.16±0.301	H. 67.1%; T. 73.0°
Small celluloid disks (a)	25	5.19±0.008	±0.062±0.006	1.20±0.114	H. 56 %; T. 72.1°
Small celluloid disks (b)	25	5.18±0.009	±0.067±0.006	1.29±0.123	H. 81 %; T. 73.6°

[1] Relative humidity.

[2] Temperature.

Since paper is evidently subject to considerable error when used for this method, we have searched for other substances which might replace it with advantage. The best material that we have discovered for this purpose is the celluloid composition used for photographic films which is known as 'Eastman Kodaloid, no. 3.' We have subjected it to the same series of tests as those used for the paper, employing the same instruments and balances and making the tests on the same days. The results are given in tables 2 and 3. Celluloid disks,

approximately 1.8 cm. in diameter, cut at random from 'Kodaloid' sheets, show coefficients of variability of 0.31 to 0.33 per cent as compared with about eight times this variability in similar-sized paper disks. Small celluloid disks show coefficients of variability ranging from about 1.2 to 1.3 per cent as compared with 2.85 to 3.6 per cent in similar-sized paper disks, or about one-half as much proportional error.

We have further tested the uniformity of thickness of these materials by making fifty consecutive readings of thicknesses of sheets at points taken at random with a Schopper automatic

TABLE 3

Variability in thickness of paper and celluloid

ITEM	NUMBER OF OBSERVATIONS	MEAN THICKNESS (IN 0.01 MM.)	STANDARD DEVIATION (IN 0.01 MM.)	COEFFICIENT OF VARIABILITY (PER CENT)	NOTES
Paper	50	15.13±0.036	±0.378±0.026	2.50±0.02	T.[1] 65.5°; H.[2] 82.0%
Celluloid	50	13.47±0.021	±0.218±0.015	1.62±0.01	T. 65.5°; H. 82.0%

[1] Temperature.

[2] Relative humidity.

micrometer reading to 0.01 mm. These readings were made on the same day as the measurements of paper thickness, with precautions against personal error mentioned above. The results are shown in table 3, and indicate that the error due to variations in sheet thickness is about two-thirds as great for celluloid composition as for standard ledger paper.

Further advantages in the use of celluloid composition as compared with paper are that the former is transparent and therefore may be used for tracings from x-ray plates and the like, that areas outlined on the material with a sharp stilus may be separated from the sheets by giving them a sharp tap, thus avoiding some of the additional error involved in cutting out areas after they have been outlined, and that it may be secured in small sheets or in large rolls as desired.

SUMMARY

A quantitative study has been made of the magnitude and sources of error in the usual methods of determining irregular areas in biological work. It has been found that the planimetric method is quite inaccurate, particularly for small areas. The area-weight method, when carried out with the use of bond or ledger paper, is much more accurate than the planimetric, but still is subject to errors which cannot be disregarded in careful quantitative work. The area-weight method carried out with celluloid composition sheets is more accurate than the same method when paper is used, and this method is recommended to investigators whose problems involve the very accurate determination of areas of irregular outlines.

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